THE UNIVERSITY OF ALBERTA

SEDIMENTOLOGY AND TAPHONOMY OF THE OLDMAN FORMATION (CAMPANIAN), DINOSAUR PROVINCIAL PARK, ALBERTA

by

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Sedimentology and Taphonomy of the Oldman Formation (Campanian), Dinosaur Provincial Park, Alberta", submitted by Peter Dodson, B.Sc., in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

Sediments of the Upper Cretaceous (Campanian) Oldman Formation at Dinosaur Provincial Park, Alberta, have yielded an exceedingly rich fauna of dinosaurs. The molasse sediments are of fluviatile origin, and show characteristics of both meandering and braided channels. Fossil molluscs, plants, and diverse salamanders indicate that Oldman sediments were deposited in freshwater, and the very sparse agglutinated Foraminifera recovered fail to controvert this conclusion. Annual growth rings in wood and vertebrae of _Champsosaurus_ demonstrate that the climate was seasonal, and current botanic interpretations suggest that the climate was an equable, warm temperate one. Dinosaurian remains are found representing all stages of decomposition, from complete skeletons to isolated bones. They are common in channel sediments and rare in overbank deposits, suggesting that the animals preserved died in the waters of channels. In lieu of modern observations on the decomposition of tetrapods, stages of progressive decomposition of dinosaurs are inferred from the condition of fossils collected from the Park. Disarticulated small bones occur at interfaces between claystone and sandstone in which the sandstone lies above the claystone, and also in intraformational conglomerates. Ceratopsians are identified as dwellers of the swampy lowlands along with hadrosaurs. Hadrosaurs, ceratopsians, and possibly even carnosaurs spent significant portions of their daily lives in water. These dinosaurs did not breed in "uplands", but possibly in dry areas lateral to the streams.

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ACKNOWLEDGEMENTS

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INTRODUCTION

Early in this century, in 1910, a field party of the American Museum of Natural History directed by Barnum Brown began exploration of what have proved to be some of the richest dinosaur beds in the world, exposed in badlands cut into Upper Cretaceous continental sediments of the Oldman and Edmonton Formations by the Red Deer River of Alberta. The Geological Survey of Canada entered the search for fossils in 1912 with a party headed by C.H. Sternberg, assisted by his three sons, George F., Charles M., and Levi, each of whom eventually conducted parties of his own. The Royal Ontario Museum began collecting in 1918, with Levi Sternberg at the head for many seasons. The museums at New York, Ottawa and Toronto amassed fine collections of fossils from the Oldman Formation, from which specimens have been traded all over the world. By 1967, at least 320 articulated specimens had been found (Russell, 1967a). An excellent account of the history of collecting dinosaurs in western Canada is given by L.S. Russell (1966), and Langston (1965) presented an extensive bibliography of fossil vertebrates from Alberta.

In 1936, C.M. Sternberg returned to the vicinity of Steveville and relocated and identified over 100 of the original quarries. At each he placed a brass plaque on a steel stake set in concrete. He published a map (Sternberg, 1950) marking the position of each stake and identifying each quarry. Thus, the area is unique, not only for its richness in fossils, but also for providing the precise location of so many quarries. The Province of Alberta established Dinosaur Provincial Park (hereafter referred to as the Park) in 1956, which, with an area of 22,000 acres, encompasses all but three of Sternberg's quarries (Fig. 1).

This area provides a unique opportunity to relate the occurrence of vertebrate (especially dinosaur) fossils to the sedimentary conditions

that prevailed, as determined by detailed lithological investigation of each locality. Such observations have rarely been made in the past, as collectors have failed to recognize the importance of the information obtainable. The price for such inattention to detail is error in paleoecological interpretation (Efremov, 1940). The study of taphonomy, an aspect of general paleontology (Brouwer, 1967), is closely coupled with sedimentology, a field of geology that has enjoyed a renaissance in the last decade or so. But, as Efremov (1953) observed, sedimentologists have neglected fossil-bearing rocks because they have considered them adequately characterized by their fossils!

The object of this research is to interpret the sedimentary conditions of the Park during Oldman time, including a qualitative assessment of the freshness or salinity of the environment, and to describe the taphonomy of the fossil-bearing rocks. The results derive from two and a half months work in the field during the summer of 1968 and three weeks in 1969. During this time, 84 of Sternberg's quarries were located; 9 were not searched for because the specimens were not identified on the map (Sternberg, 1950) or, in one case, because of relative inaccessibility of the quarry; 19 quarries were not located because the stakes were missing (through slumping or vandalism), because of failure to read the map correctly or failure of the map to record localities correctly. At each quarry located, the stratigraphic section was measured in the immediate vicinity, and was extended vertically as far as exposure and topography permitted; lithology of the quarry was noted, and orientation of the quarry was recorded (insofar as it revealed orientation of the fossil removed) and the direction of the current was measured if cross-strata were nearby. Each section was photographed.

Each section measured is illustrated in Fig. 2, and described in Appendix A.

GEOLOGICAL SETTING

The Cretaceous Period was a time of great marine transgressions, and its seas were rivaled in extent only by the epeiric seas of the Ordovician. By Late Cretaceous times, a seaway extended from the Gulf of Mexico to the Arctic Ocean (Weimer, 1960; Tourtelot and Rye, 1969). Deposits of this sea are found as far west as eastern British Columbia and eastern Arizona, and as far east as Manitoba and western Iowa.

Throughout much of the area covered by the seas, cratonic conditions persisted and relatively thin sedimentary covers accumulated, but along the linear western margin, in the Rocky Mountain Miogeosyncline, strong subsidence took place and thick deposits of sediments collected (Clark and Stearn, 1960). Thicknesses of Upper Cretaceous sediments thus range from less than 1,000 ft. beneath the eastern plains to more than 19,000 ft. in southwestern Wyoming (Weimer, 1960). The major source of the clastic sediment was the land uplifted to the west by pulses of the Laramide Orogeny; volcanoes in the tectonic highland contributed significant volumes of detritus as well. Materials shed from these terrains were carried eastward by streams, and formed extensive deltas adjacent to the seaway. The position of the shoreline was determined by the balance between sedimentation and subsidence. When sedimentation outstripped subsidence, deltaic conditions spread eastward far out into the area occupied by the plains today; when subsidence exceeded sedimentation, marine shales were laid down as far west as the Foothills of the Rocky Mountains. Thus Upper Cretaceous sediments on the western plains form an alternating series of continental sandstone and marine shale formations, to the east of which lie uninterrupted marine sediments (Weimer, 1960; Williams and Burk, 1964).

The tectonic framework that controlled Late Cretaceous sedimentation had a close analogue in the Appalachian Geosyncline of the east. In the Late Devonian, lands uplifted by the Appalachian Orogeny shed sediments westward across New York State and Pennsylvania. Extensive continental conditions prevailed adjacent to the uplift; these passed gradationally to the west into marine conditions on the craton. The term, tectonic delta complex, has been applied to the Catskill delta so formed (Friedman and Johnson, 1966; Johnson and Friedman, 1969). This seems a useful term in the discussion of western North American Late Cretaceous sediments, in recognition of the synorogenic, molasse nature of the deposits (Van Houten, 1969).

The sediments of the Belly River or Judithian (L.S. Russell, 1964; D.A. Russell, 1967b) delta form a clastic wedge 2300 ft. thick in the Rocky Mountain Foothills (Lerbekmo, 1961), that thins to 900 ft. on the plains of Alberta (Williams and Burk, 1964). In eastern Alberta, the sandstones are intercalated with marine shales, although some of the sandstones persist well into Saskatchewan (Shaw and Harding, 1954; Williams and Burk, 1964).

STRATIGRAPHIC NOMENCLATURE OF THE OLDMAN - BELLY RIVER FORMATIONS

This study deals primarily with the lower Upper Campanian Oldman Formation, which documents part of what Weimer (1960) considers the third regressive marine phase of the Late Cretaceous. Radiometric dates from the base of the overlying Bearpaw Formation, a marine shale documenting the fourth transgressive marine phase of the Late Cretaceous, give an average age of 72 to 73 million years (Folinsbee *et al.*, 1965). No date is yet available from the underlying Pakowki Shale (third transgressive phase). Since the Bearpaw Formation and the Oldman plus Foremost Formations are both about 900 ft. thick on the plains (Russell, 1940a), and since continental sandstones accumulate at a much higher rate than do marine shales, the interval represented by the Oldman Formation was significantly less than the roughly six million year span attributed to the Bearpaw Formation. This conclusion is reinforced by Jeletzky's (1968) zonation of the sediments of the western plains. He showed that the *Bacculites compressus* zone, to which the Bearpaw is referred, spans most of the Upper Campanian. The *B. obtusus* zone of the Pakowki Formation lies at the base of the Upper Campanian. The Oldman and Foremost Formations are therefore bracketed in an apparently short interval relative to that represented by the Bearpaw.

The name, Oldman, is closely linked to the name, Belly River; the latter has had an unsettled history due to a stratigraphic error in its definition. Both names have been applied to the fossil-bearing rocks exposed at Dinosaur Provincial Park, the term Oldman having been used as a member and as a formation, Belly River as a formation and as a group. George Dawson, the pioneering geologist of the early western boundary survey, described in 1885 the Belly River series as "composed

of an upper, or 'pale' and a lower or 'yellowish' portions, and consisting of alternations of sandstones, sandy clays, shales and clays" (Dawson, 1885, p. 112c). He considered the upper portion to be a freshwater unit, and the lower portion to be of brackish-water character. His Belly River series was bounded above by the "Pierre shales" (Bearpaw Formation of current usage), and below by the "Lower dark shales" (Colorado Group). He failed to recognize that a major marine phase, represented by the Pakowki Shale, interrupted continental conditions during the interval encompassed by his Belly River series. In 1905, Stanton and Hatcher traced the Judith River Formation and the Claggett Shale from Montana into Alberta in the valley of the Milk River (Stanton and Hatcher, 1905). They demonstrated the equivalence of the Judith River Formation with the upper part of Dawson's Belly River series, and the presence of an important marine interval equivalent to the Claggett Shale. Dowling (1917) formalized the shale so recognized as the Pakowki Shale, and the castellated sandstones below as the Milk River Sandstone. He applied the name, Foremost, to Dawson's yellow beds. Attempting to clarify Dawson's term, he defined the Belly River series as consisting of, in descending order: "Pale beds, Foremost beds, Pakowki shales, Milk River sandstone". He therefore chose to emphasize the stratigraphic interval initially indicated by Dawson.

Williams and Dyer (1930), on the other hand, chose to emphasize Dawson's environmental interpretation, and accordingly defined the Belly River Formation as "being composed of the continental beds lying between the Pakowki and the Bearpaw", in which the pale beds and the Foremost have the status of members. In response to the ambiguity surrounding the term, Belly River, Russell (1940a) elevated the pale

beds and Foremost members to the status of formations, designated the former as the Oldman Formation, and advocated abandonment altogether of Dawson's troublesome name.

The Oldman and Foremost Formations are readily mappable units distinguishable in outcrop throughout much of southern Alberta, particularly in the valleys of the Red Deer, South Saskatchewan, Oldman, Bow and Milk Rivers (Williams et al., 1928), so the designation of these formations is useful, and has achieved a measure of acceptance, notably among vertebrate paleontologists. However, the name Belly River persists among petroleum geologists (for instance, Shaw and Harding, 1954; Williams and Burk, 1964). In the Foothills, not only are Oldman and Foremost units not distinguishable from each other, but the Pakowki Formation is either altogether absent or present as a thin horizon 10 to 20 ft. thick, so that the Milk River Sandstone interfingers with the Belly River Formation (Lerbekmo, 1961). Thus it appears that here continental clastic sedimentation continued without major interruption throughout the entire interval encompassed by Dawson's original definition.

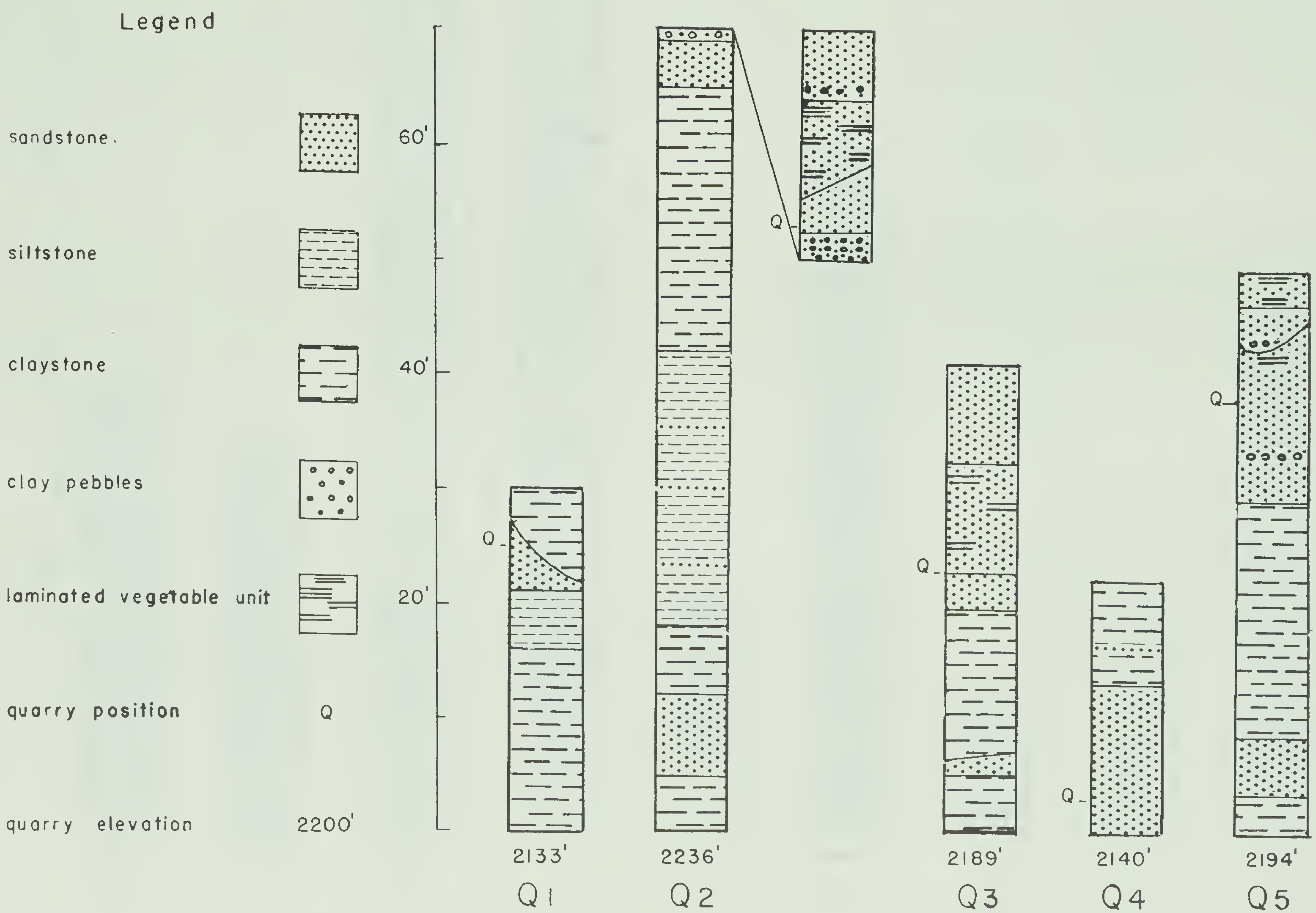
In conclusion, it seems impractical to abandon the term, Belly River, but its use on the plains should be restricted to the status of a group.

SEDIMENTOLOGY

The sediments of the Oldman Formation constitute a molasse deposit, corresponding to Pettijohn's (1957, p. 618) application of the term to sands and shales that are "immature products of denudation". Although no petrographic work has been published on the sediments of the Oldman Formation on the plains, observations on the petrology of the Belly River Formation of the Foothills (representing the proximal portion of the delta of which the Oldman Formation is the distal part) by Lerbekmo (1963) are generally applicable. Lerbekmo characterized the sandstones of the Belly River Formation as consisting of about one half quartz and quartzite, one third rock fragments and one fifth feldspars. This composition plots as a lithic sandstone with his scheme of classification, or as a subgreywacke with that of Pettijohn (1957). Accessory minerals, about one per cent of the rock, and dark rock fragments, are sufficiently abundant to give the otherwise light gray sandstone a "salt and pepper" appearance.

Whereas in the Foothills, mudstones are dominant in the upper two thirds of the Belly River Formation (Lerbekmo, 1963), sandstones predominate in the Park, and account for about 70% of the sediments in the sections measured (Fig. 2). The poorly consolidated sandstones of the Park show abundant cross-stratification in which the foreset strata may be defined by indurated laminae, plant-rich laminae, or argillaceous laminae. Clay pebble conglomerates, with clast size generally ranging from one quarter to one half an inch, are frequently encountered. Evidence of plant remains is ubiquitous, particularly in the form of laminated units up to 1 ft. thick (as in section Q3), but usually 2 to 6 in. thick (Fig. 3); the vegetable material is broken up and mixed

Fig. 2. Measured Sections



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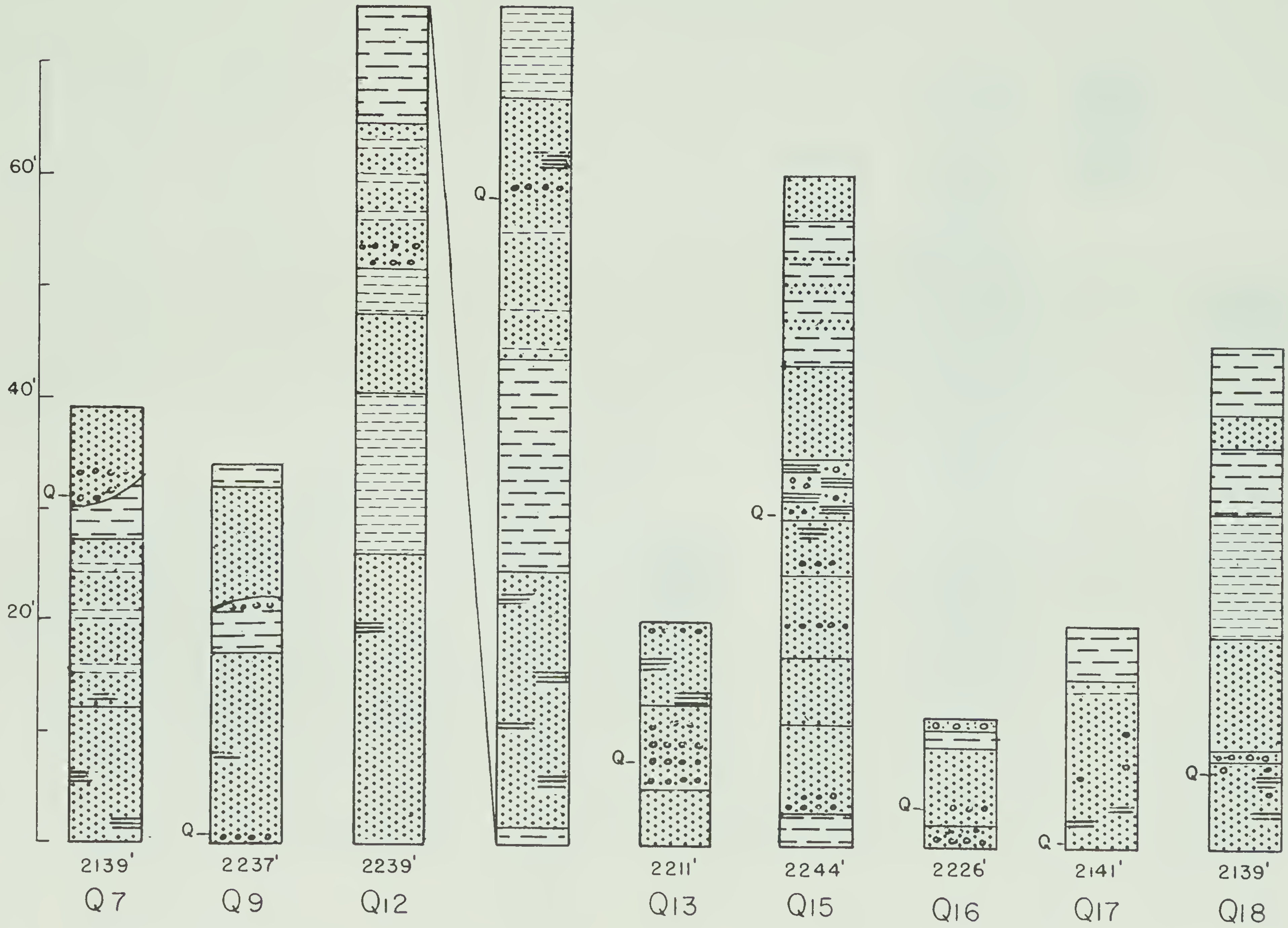
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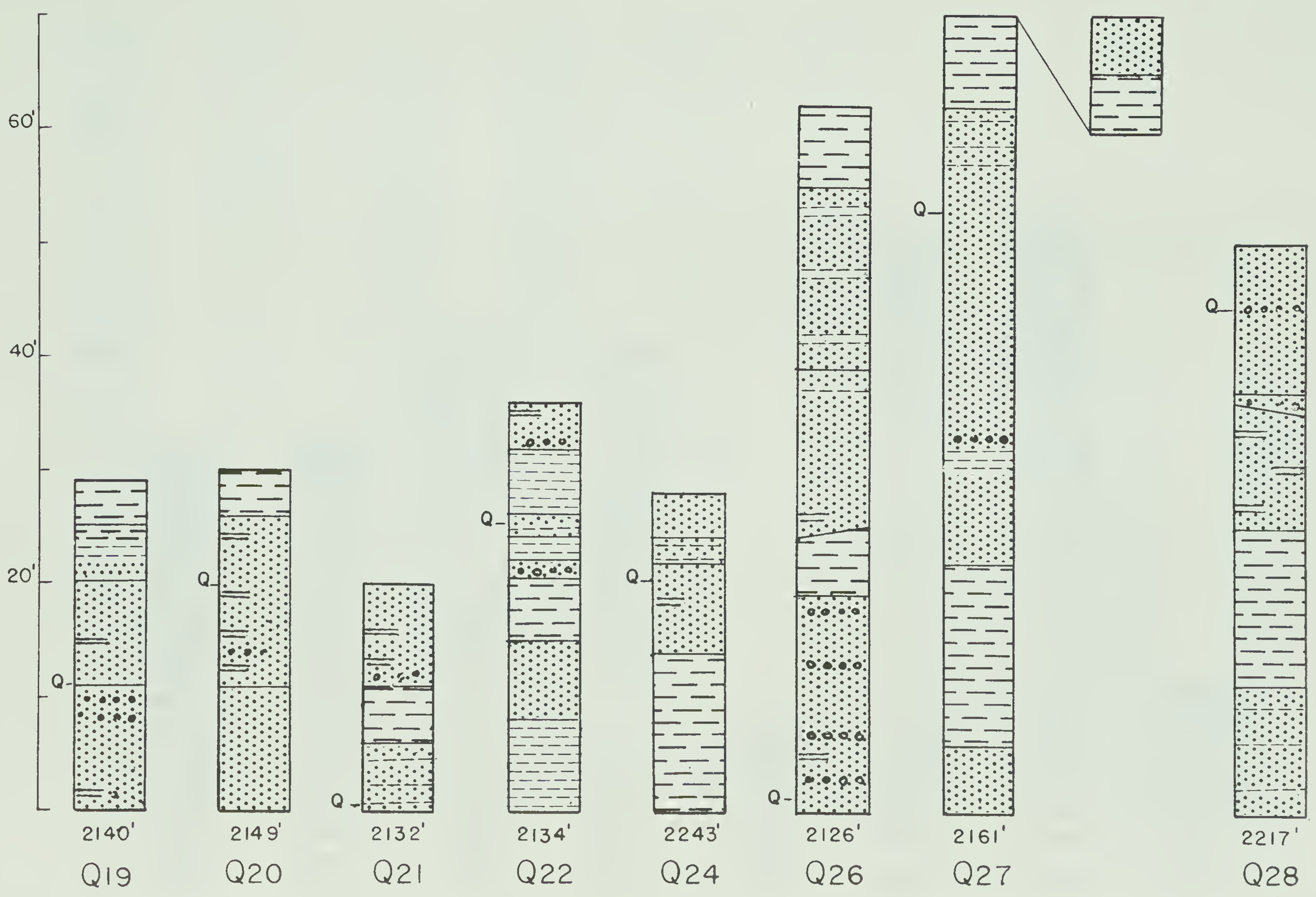
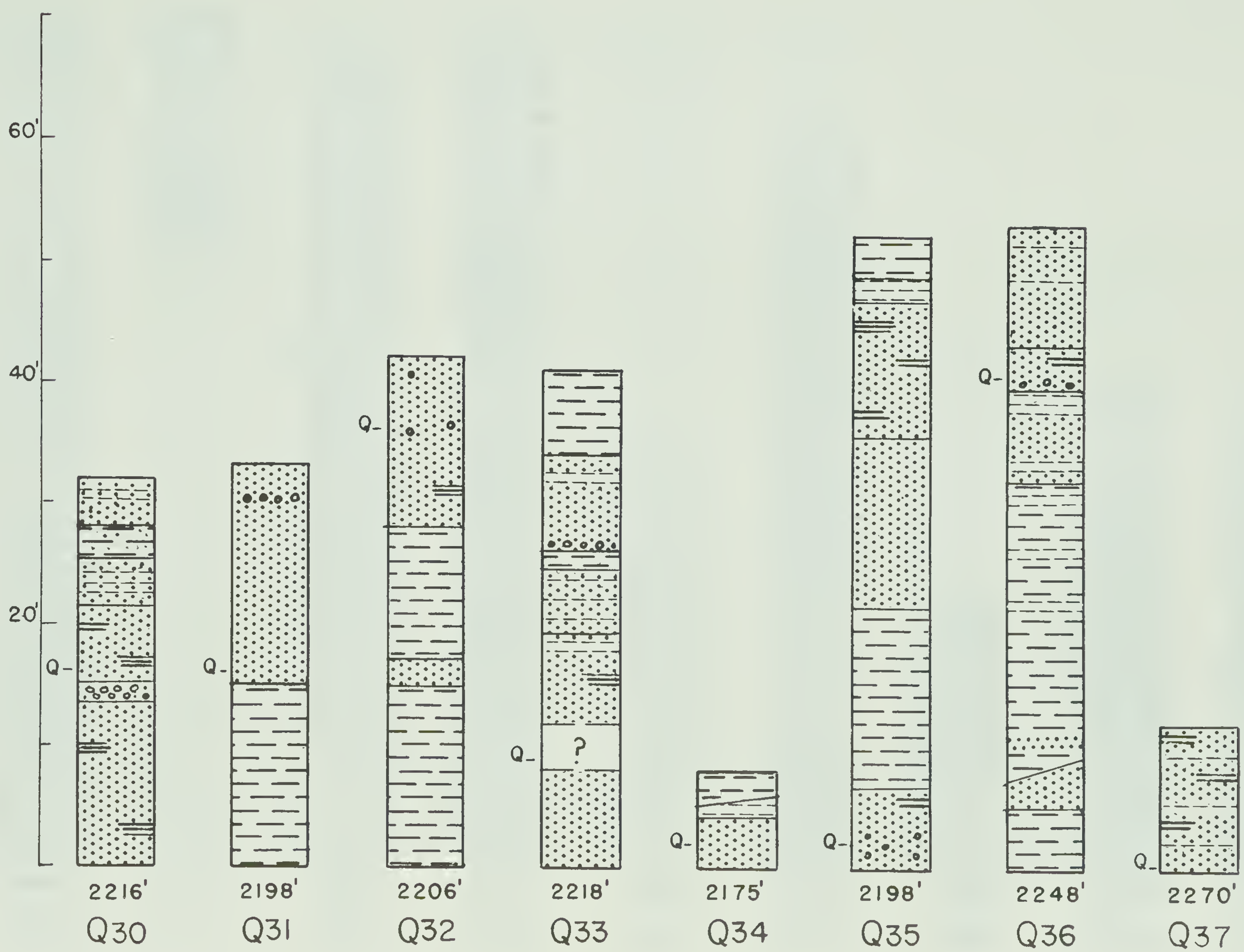
40'
20'
Q
2139'
Q7
2237'
Q9
2239'
Q12
2211'
Q13
2244'
Q15
2226'
Q16
2141'
Q17
2139'
Q18

Fig. 2. cont.



60'
40'
20'
Q
2140'
Q19
2149'
Q20
2132'
Q21
2134'
Q22
2243'
Q24
2126'
Q26
2161'
Q27
2217'
Q28

Fig. 2. cont.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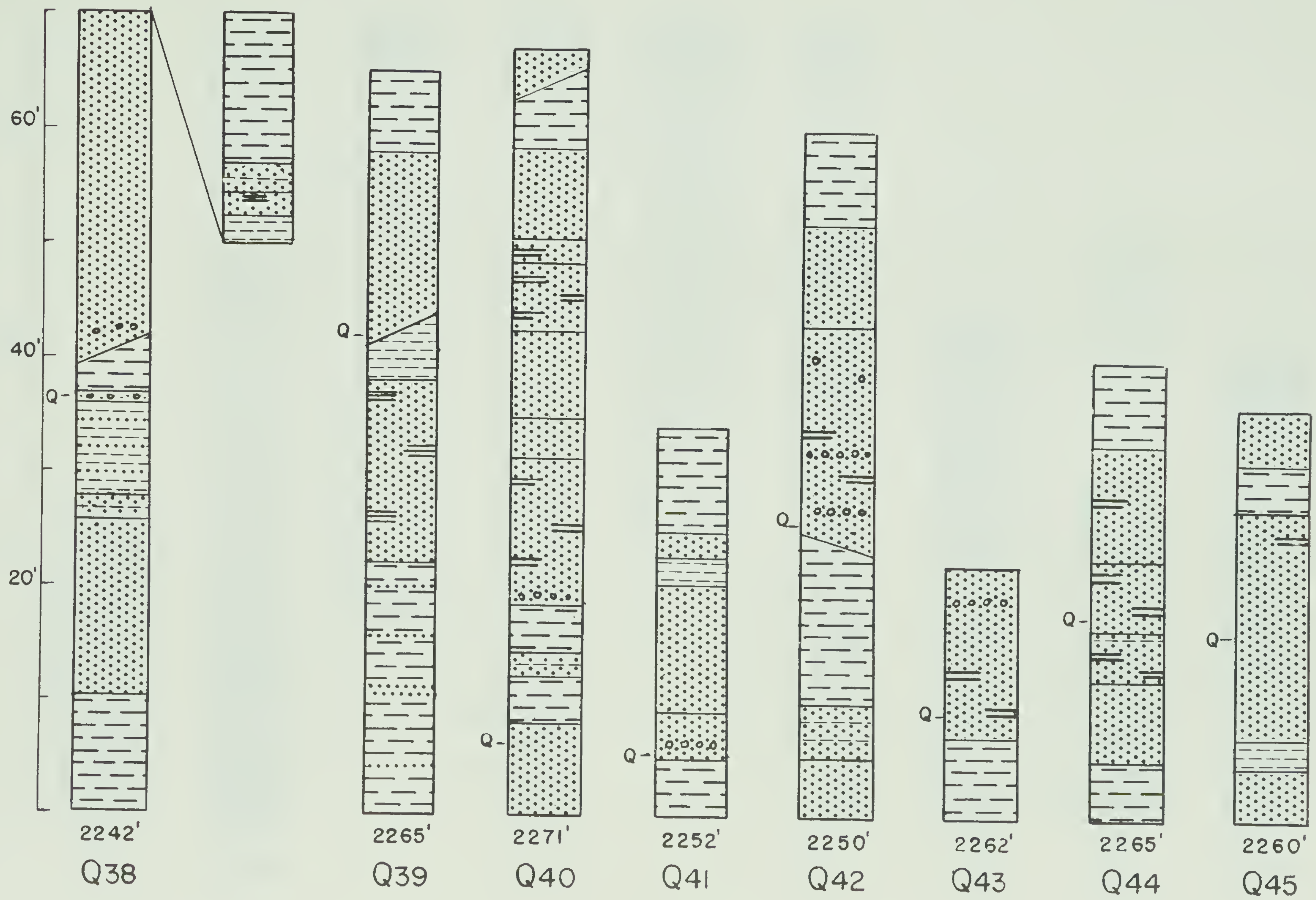
2216'
Q30
2198'
Q31
2206'
Q32
?
2218'
Q33
2175'
Q34
2198'
Q35
2248'
Q36
2270'
Q37

Fig. 2. cont.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Q38
2265'
Q39
2271'
Q40
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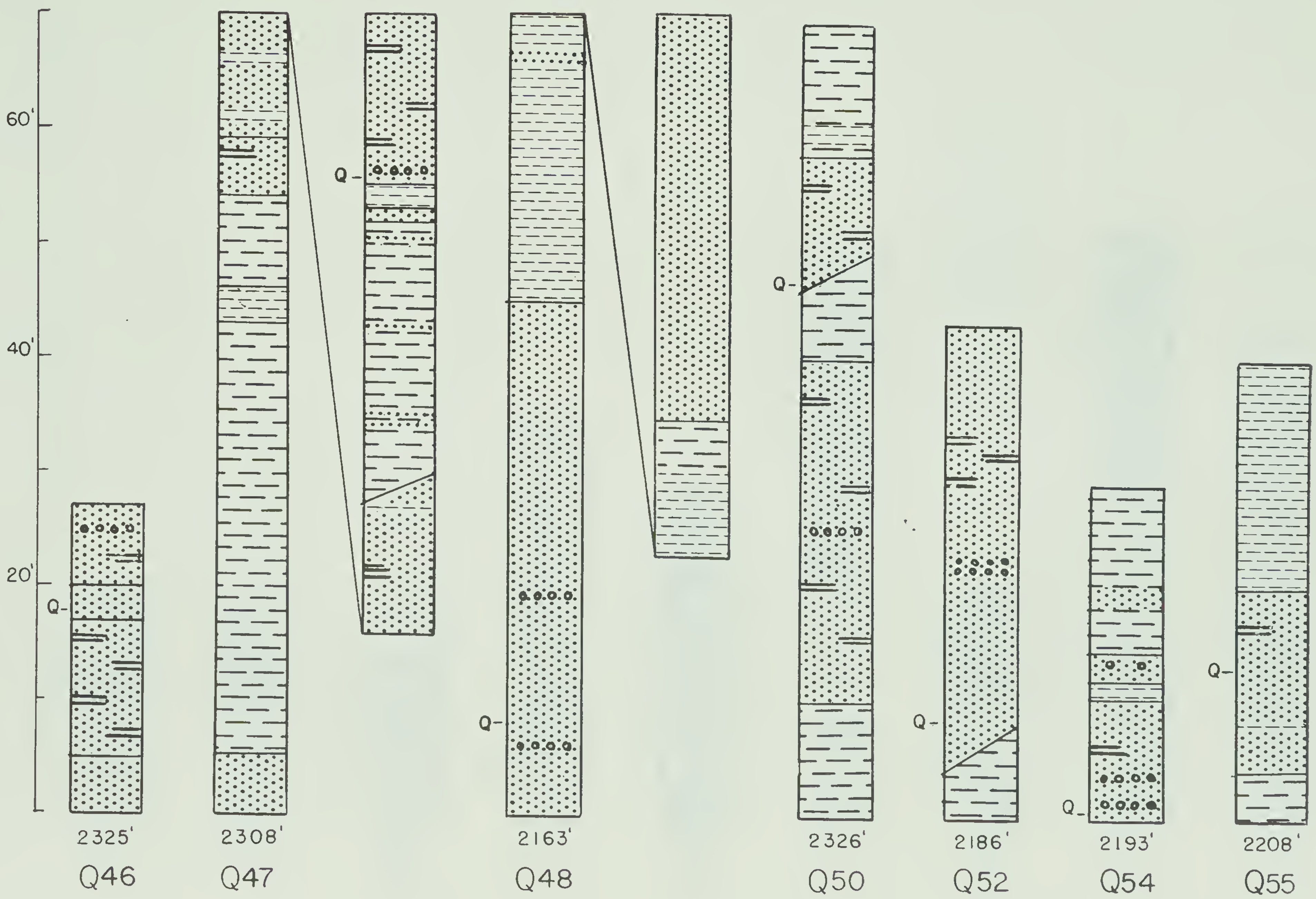
Q43
2265'
Q44
2260'
Q45

Fig. 2. cont.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2308'
Q47
2163'
Q48
2326'
Q50
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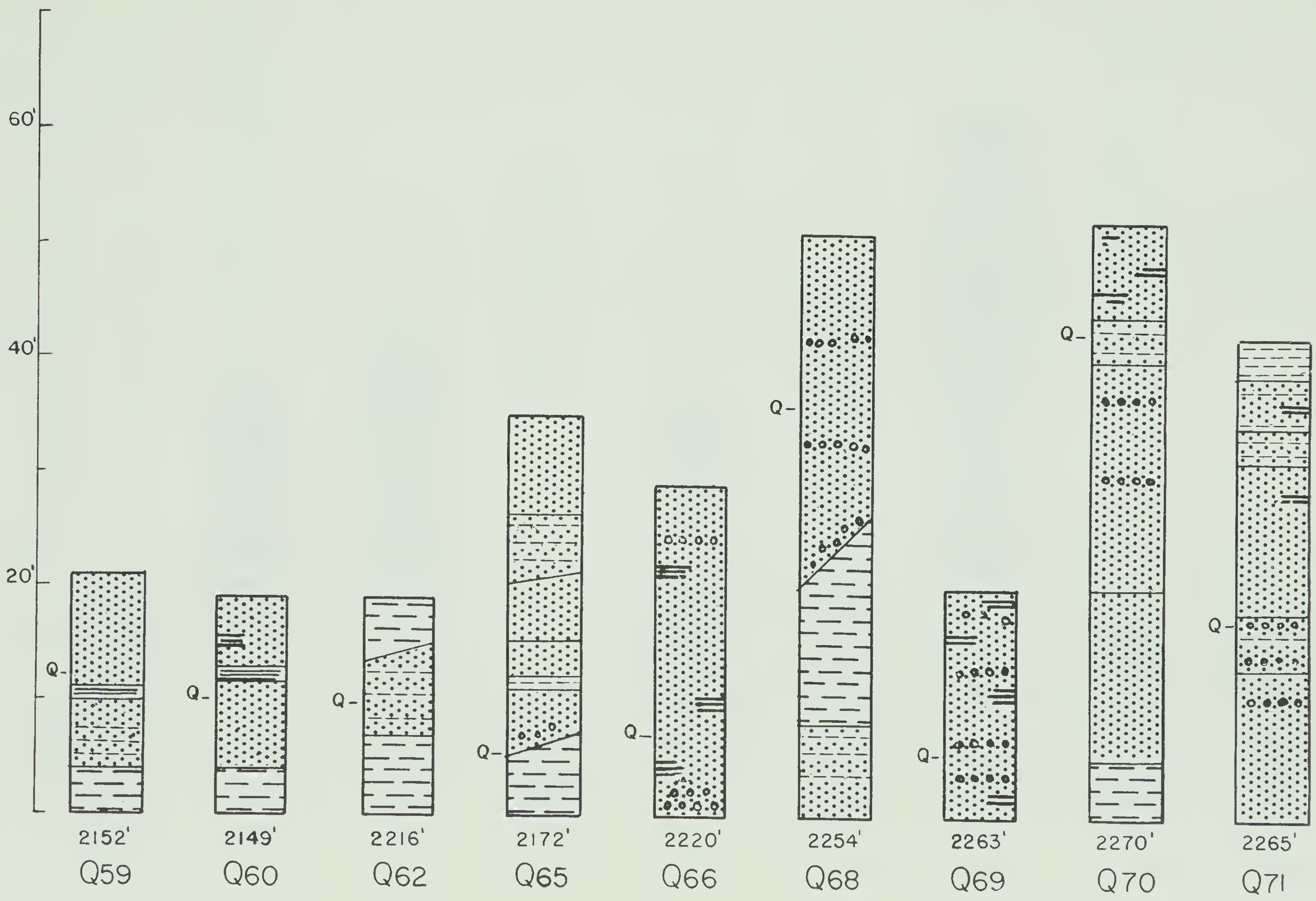
Q52
2193'
Q54
2208'
Q55

Fig. 2. cont.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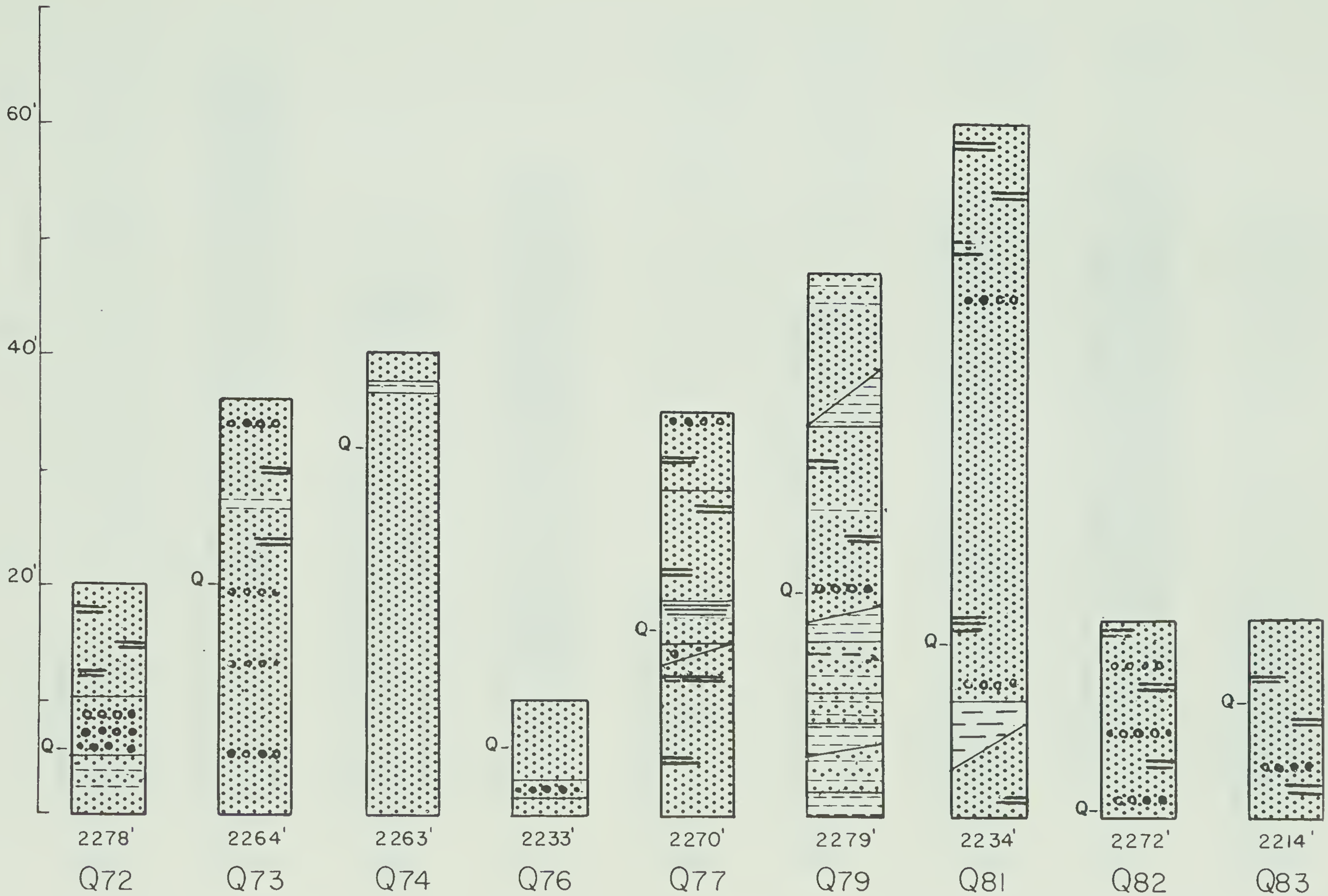
Q68
2263'
Q69
2270'
Q70
2265'
Q71

Fig. 2. cont.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2263'
Q74
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Q76
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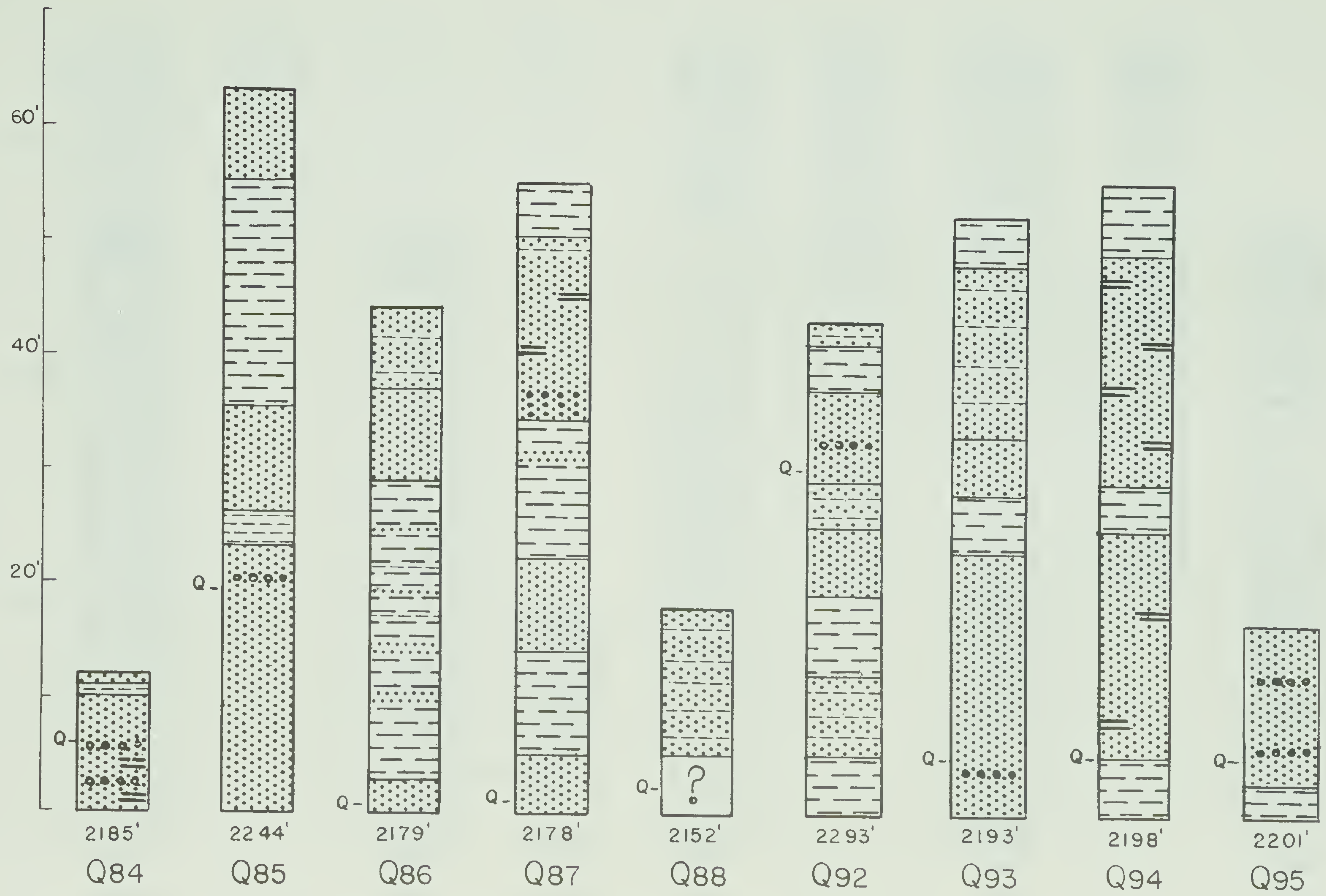
Q77
2279'
Q79
2234'
Q81
2272'
Q82
2214'
Q83

Fig. 2. cont.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40'
20'
Q-
Q-
Q-
Q-
Q-
Q-
Q-
Q-
Q-
?
2185'
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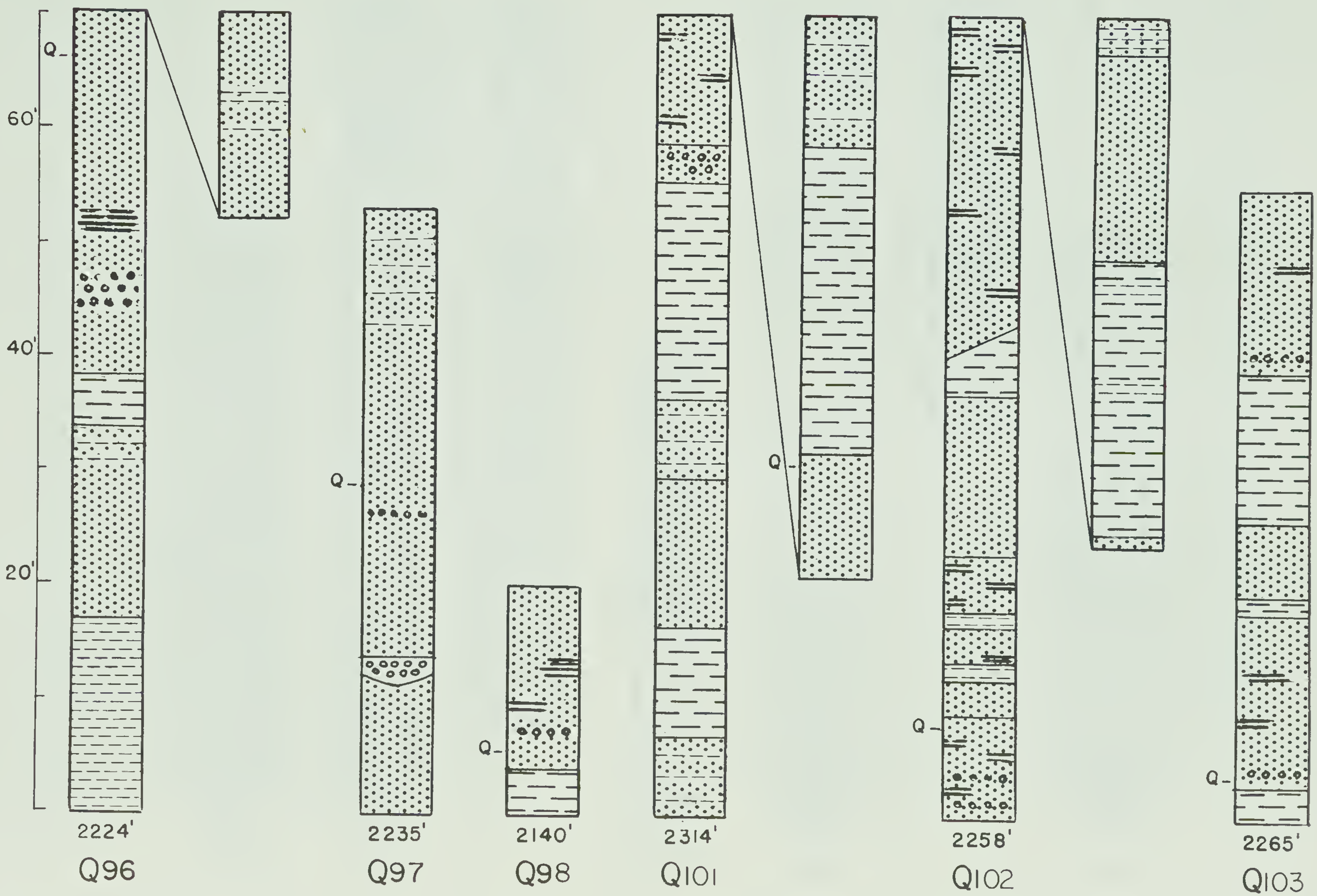
2244'
Q85
2179'
Q86
2178'
Q87
2152'
Q88
2293'
Q92
2193'
Q93
2198'
Q94
2201'
Q95

Fig. 2. cont.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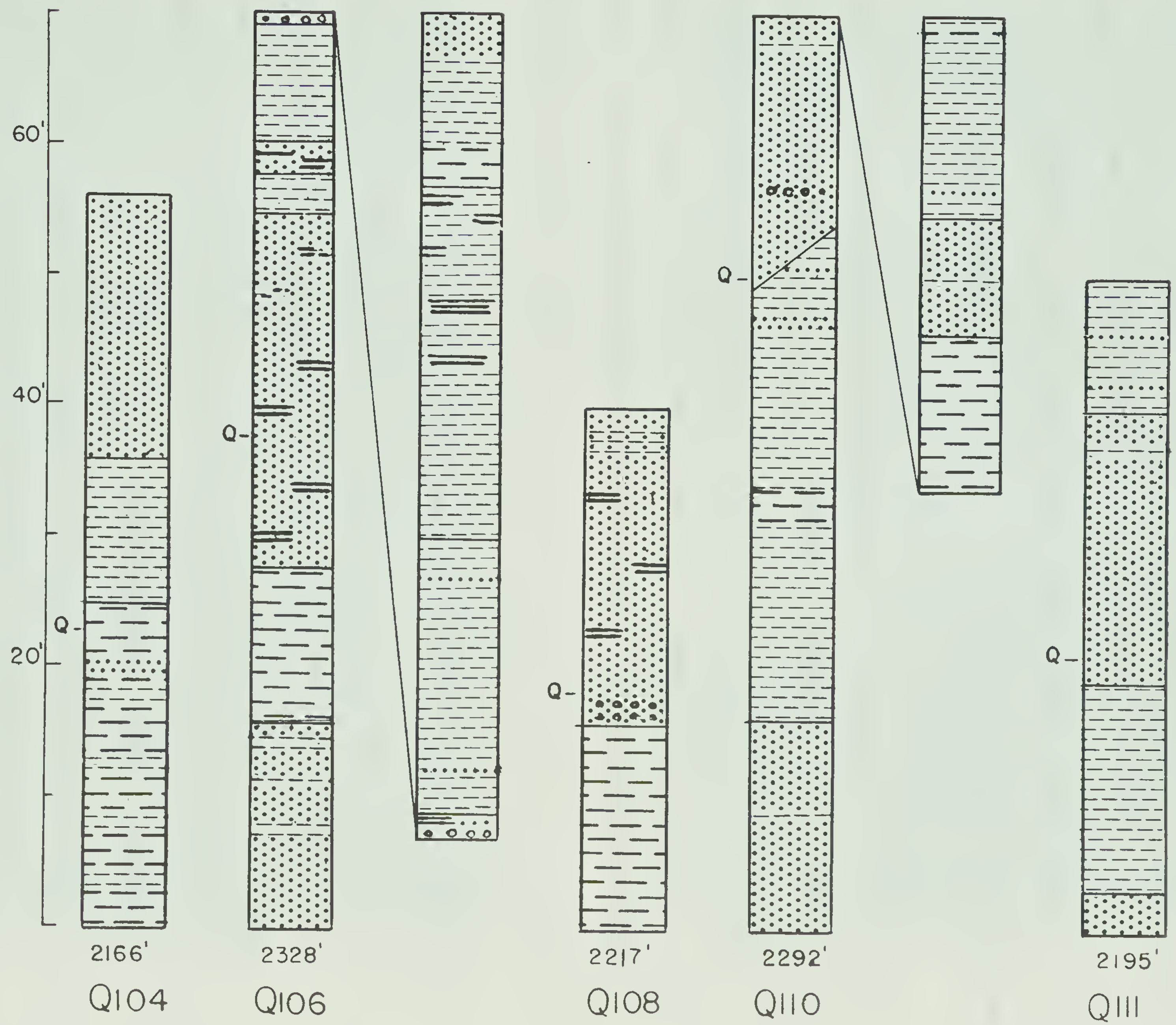
40'
20'
Q
2224'
Q96
2235'
Q97
2140'
Q98
2314'
Q101
2258'
Q102
2265'
Q103

Fig. 2. cont.


60'
40'
20'
Q-
Q-
Q-
Q-
Q-
2166'
Q104
2328'
Q106
2217'
Q108
2292'
Q110
2195'
Q111

with considerable quantities of detrital sediment and therefore is not strictly coal. True coals are rare; the only one encountered in the Park is an 18 in. thick bed, near the top of section Q106, close to the Bearpaw contact. Fossil logs are found throughout the range of exposures, but are not common. Locally, good impressions of plants are found, most often in silty sediments.

The sandstones, except when cross-stratified, tend to be structureless; bedding planes are usually obscure or lacking. Sandstone units range in thickness from less than an inch to more than 50 ft. In all but the thinnest of these, evidence of erosional truncation and extensive reworking of materials is commonly observed. The grain size is invariably that of fine sand or finer (Wentworth scale); thus the sandstones are significantly finer than their equivalents of the Foothills, the majority of which are near the border between fine and medium sand (Lerbekmo, 1963).

A striking feature of the Oldman Formation is the lack of lateral continuity of units; few can be traced more than a quarter of a mile, and many change character within 50 yds. or less (Fig. 4). A possible exception is a persistent clay horizon in the vicinity of quarries 41 to 44, which may correlate with a clay at about the same elevation near quarries 80 to 85, three miles to the east (Fig. 1). Thick sandstones that appear to be laterally persistent, invariably prove on closer inspection to consist of multiple sub-units, with erosional relationships between and within. Thus they do not necessarily represent laterally contemporaneous units of sedimentation useful for purposes of correlation. Conspicuous marker horizons are absent. Although the sands and clays are highly montmorillonitic,

Fig. 3. Laminated Vegetable Units in Sandstone at Quarry 3

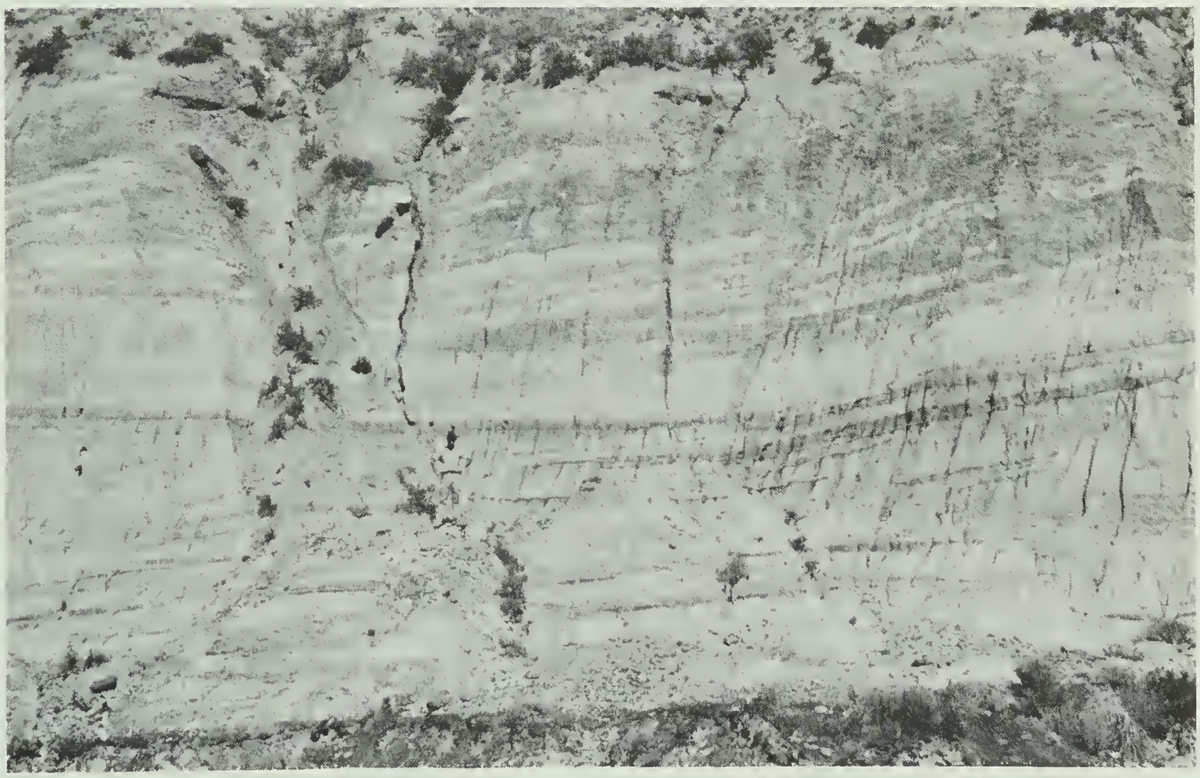


Fig. 4. Lensing Out of Units opposite Quarry 40; note figure for scale

there are no bentonites here, in contrast to the Foothills section, where ashes up to 4 ft. thick occur (Lerbekmo, 1963). Apparently, any ashes that may have fallen in the Park were reworked and incorporated into the enclosing sediments.

The argillaceous sediments, which are soft, non-fissile claystones and mudstones, are gray, or with moderate vegetable content, chocolate brown. They constitute about 30% of the sediments in the Park (Fig. 2). The seven shales and mudstones from the Foothills examined by Lerbekmo (1963) consisted of 30 to 100% illite, 0 to 65% montmorillonite and mixed layer clays, and 0 to 20% kaolinite or chlorite. Attaining a maximum thickness of 30 ft. in the sections measured (Fig. 2), the argillaceous sediments are thinner than the thickest sandstones, but seem more persistent and probably represent more nearly synchronous intervals deposited under conditions of relatively low energy. The claystones generally do not exhibit internal structures. The expansion of montmorillonite upon hydration causes the claystones to form on weathering a characteristic "popcorn" surface.

Cross-stratification

Abundant cross-stratification of several different types is present in the sandstones. Those cross-strata most frequently indurated, and thus suitable for directional studies, are dominantly of the planar (McKee and Weir, 1953) or beta (Allen, 1963) type, with a horizontal lower bounding surface. Also common is the simple (McKee and Weir, 1953) or alpha (Allen, 1963) type, which has a planar non-erosional lower bounding surface (Fig. 5). Modal thickness of sets is between 6 in. and 2 ft., with a maximum of about 4 ft. Some have concave

upward foreset laminae defined by vegetable or argillaceous laminae, are concordant at the base, and are of small scale according to Allen's (1963) classification (Fig. 6). The only exception to the rule of solitary sets of cross-strata is the infrequent occurrence of cosets of ripple-drift bedding (lambda type of Allen), noted at sections Q1, Q74, and near Q76. An intruiging type, seen in the vicinity of quarries 2, 36, 47, and 111, consists of solitary, low angle foreset beds of sandstone 10 to 15 ft. high, discordantly overlying a planar non-erosional surface; the sediment enclosing the foresets is claystone (Fig. 7). They are not satisfactorily described in Allen's classification.

The mean current direction, based on measurements of 218 cross-strata (Fig. 1), and calculated by Curray's (1956) method, was 84.7°, and the standard deviation, using Pelletier's (1958) calculation is 66.3°, with a vector magnitude of 48.0% (Fig. 8). This indicates that the paleoslope dipped slightly north of east. Lerbekmo's (1963) provenance studies in the Foothills support this conclusion. He determined that sources of Belly River detritus were a sedimentary terrain of cherty carbonates, shales and sandstones, a terrain of low grade pelitic metasediments, and a terrain of volcanic and possibly plutonic igneous rocks, all of which are known to lie west and southwest of the Foothills section.

Current variance, defined as the square of the standard deviation of directional data, has been used as an environmental indicator. Potter and Pettijohn (1963) suggest, from a survey of published data on current variability related to specified environments, that variances in the range of 4000 to 6000 characterize fluvio-deltaic deposits, while

Fig. 5. Simple Cross-Strata at Quarry 48

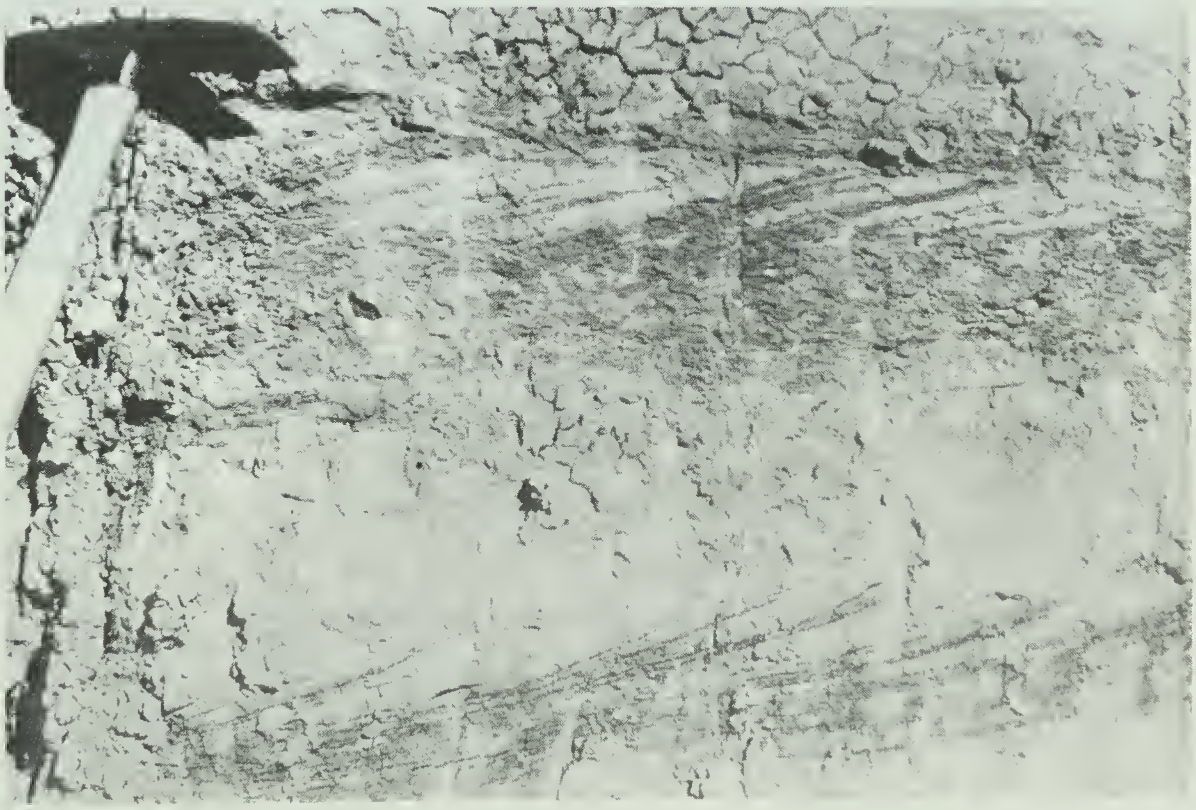


Fig. 6. Small Scale Cross-Strata at Quarry 7; foresets defined by laminae of claystone above, by vegetable laminae below

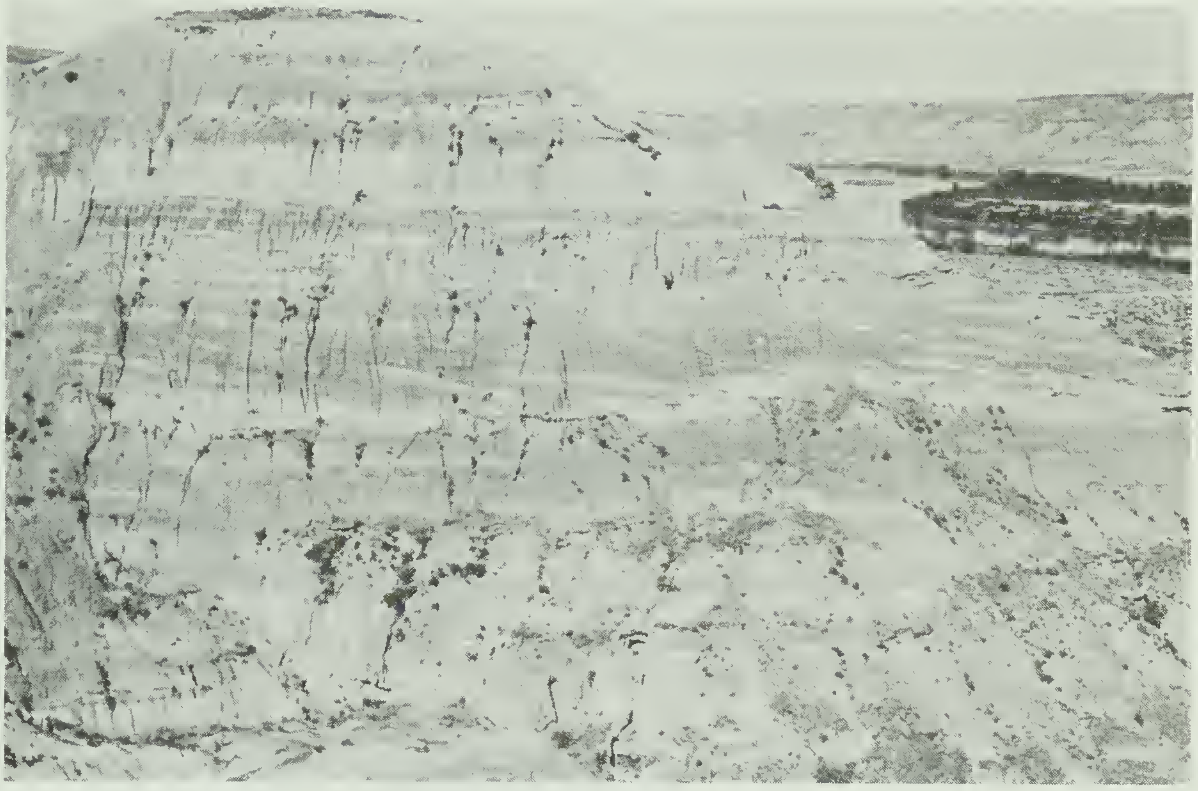


Fig. 7. Large, Low Angle Cross-Strata in Claystone near Quarry 111

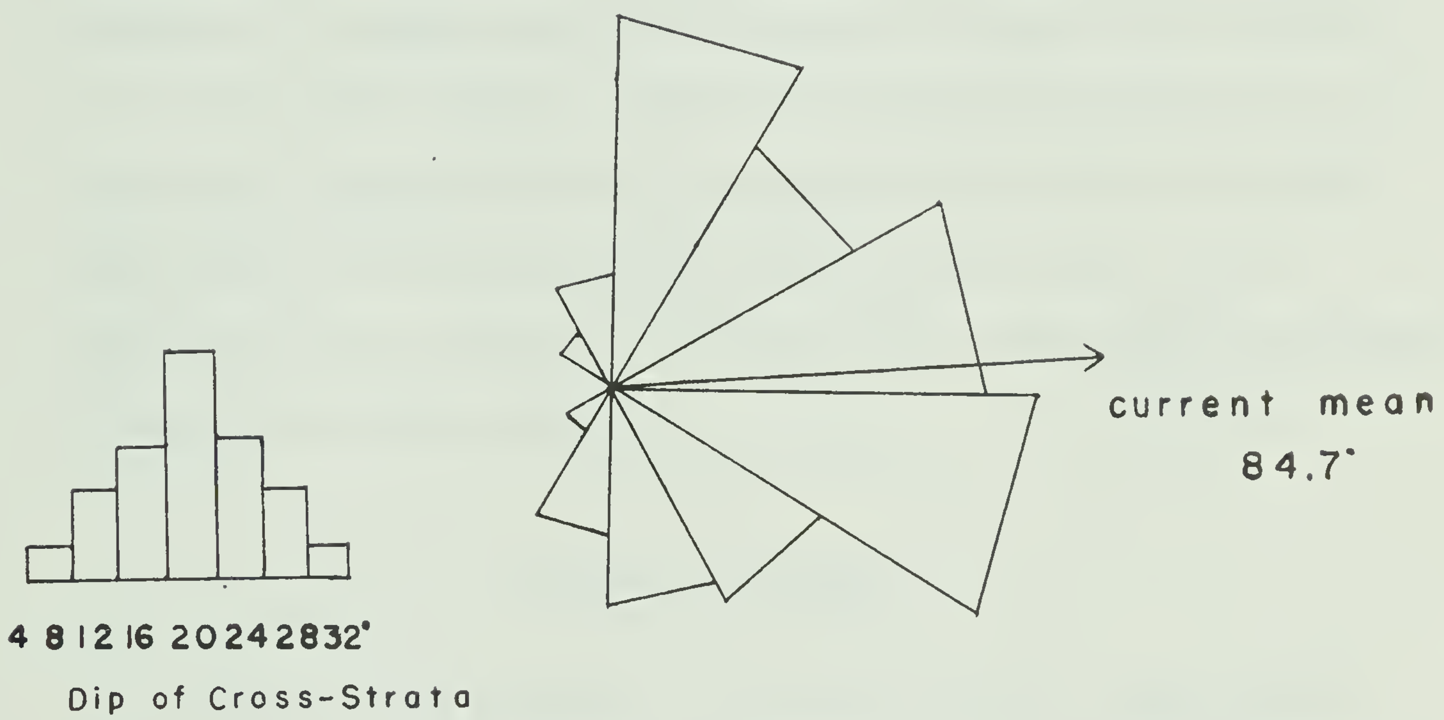


Fig. 8. Summary of Current Directions

n = 218

the range 6000 to 8000 characterizes marine deposits. As the variance calculated in this study is 4395, fluvial conditions are indicated. This view will be substantiated by an examination of the lithotopes in the following section.

The cross-strata show no significant pattern of directional variation, either in a geographic (horizontal) or stratigraphic (vertical) sense, across the area as a whole; variation of current direction at a single outcrop may be nearly as great as the variation in the entire Park (Fig. 1). The lack of significant change over the stratigraphic interval studied is consistent with Pelletier's (1958) observations of the Pennsylvanian Pocono tectonic delta, and is indicative of the constancy of tectonic control during the time required to deposit the Oldman sediments.

Fluvial Lithotopes

Allen (1965) presented a thorough discussion of the fluvial environment and its characteristic sediments. He classified alluvial sediments principally as either channel (substratum) or overbank (topstratum) deposits (Table I).

Channel-lag deposits, consisting of residual accumulations of clastic material too heavy to be moved by the current, are found in the Park. Pebbles of crystalline rocks are very uncommon in the area, and their infrequent occurrence is puzzling (found at sections Q7, Q106, near Q57). At section Q7, the base of a sandstone contains a layer of subrounded to rounded black chert and quartzite pebbles, up to an inch long, immediately above the contact with a claystone. Concentrations of clay pebbles in sandstones are abundant. These

pebbles are usually well rounded, and may reach an inch or more in diameter, but are generally one quarter to one half inch in diameter. Usually within a sandstone matrix, they occasionally overlie the claystone from which they were derived as a basal conglomerate, as at sections Q7, Q15, Q21, etc., but more frequently occur within a sandstone. Characteristic concentrations of small fossils along with clay pebbles (described in a subsequent section) are lag deposits also.

TABLE I CLASSIFICATION OF ALLUVIAL SEDIMENTS

Site of Deposition	Type of Deposit	
channel floor	channel-lag deposit	CHANNEL OR SUBSTRATUM DEPOSITS
point bar	point bar deposit	
channel bar	channel bar deposit	
point bar swale or abandoned braided channel	swale fill deposit	OVERBANK OR TOPSTRATUM DEPOSITS
levee	levee deposit	
crevasse-splay	crevasse-splay deposit	
flood basin	flood basin deposit	

(modified from Allen,1965)

Two fundamental methods of formation of clay pebbles may be distinguished: undercutting of banks by streams, and scour of basal surfaces by streams (Dunbar and Rogers, 1957; Allen, 1962; Williams, 1966). Williams (1966) demonstrated that even low shores may be potential sources of clay pebbles, so the collapse of undercut banks need not be dramatic to be effective. He also described subangular, disc shaped plates of mud

resulting from scour of relatively thick layers of dried mud in a channel. Claystone clasts such as these were occasionally found in the Park, as at section Q7. About one quarter of the 88 clay pebble horizons recorded in the field directly overlie claystones. These are interpreted as the result of basal scour of the underlying surface (Allen, 1962). The remaining occurrences of clay pebbles are interpreted as resulting from the collapse of banks. Locally, solitary claystone clasts within a sandstone are 2 to 3 ft. long, and probably resulted from collapse of a bank consisting of unusually cohesive clay.

The remaining types of channel deposit are best discussed together, for the distinction between point bar and channel bar deposits depends primarily on prior recognition of the channel form as being either meandering or braided. Such deposits represent the coarse fraction of material carried by streams. Abundant cross-strata, particularly consisting of large scale, solitary sets of various types (Allen, 1963), characterize bar deposits, and have been extensively documented (for example, Frazier and Osanik, 1961; Potter and Pettijohn, 1963; Allen, 1965). Other characteristic features of bar deposits plentifully represented in the Oldman Formation are drifted plant remains (including logs, twigs, leaves and macerated debris), and bone. Both kinds of organic debris have been reported from a Mississippi River channel deposit (Frazier and Osanik, 1961). Thus, the extensive sandstones with abundant cross-stratification so characteristic of the Oldman Formation may be confidently referred to the channel environment. Channel sediments constitute by far the most common lithotope in the Park.

However, obvious cross-sections of channels are not seen. In

view of the excellence of exposures and predominance of channel deposits, this paucity is probably real. When a channel sandstone overlies a claystone, the contact is usually horizontal, but in some cases has a low relief, probably resulting from scour. At section Q7 the relief is about 3 ft. within 10 ft. horizontally; at Q42, the relief is 2 ft. in 25; at Q65, 2 ft. in 15 (Fig. 2). The normal absence of well incised channels suggests that channels were shallow, shifting and ephemeral.

Of the overbank deposits, the levee, formed adjacent to the channel, shows features of both channel and more distal floodplain deposits. Rapid vertical interbedding of coarse with fine sediments is most characteristic (Allen, 1965). As levees are subject to considerable subaerial exposure, terrestrial plants may grow there, and evidence of rootlets may be found as tubules of oxidized iron in the sediment. Oxidation of well drained soil may lead to the formation of brown, iron-rich layers. Levees are also sites of formation of calcareous concretions, due to leaching during the formation of soils (Moody-Stewart, 1966). Such features as these are moderately common in the Park, and units displaying these are considered to be levee deposits. Interlayered coarse and fine sediments with notable ironstone exceed a total thickness of 5 ft. at sections Q15 and Q21, and at Q86 reach 25 ft. (Fig. 2). Sideritic ironstone concretions, many of which strongly resemble sideritic concretions described by Franks (1969), are common but are by no means restricted to levee deposits; they also are found in channel sandstones, and, less commonly, in claystones. Fossil rootlets are locally abundant (sections Q13, Q33, near Q55, Q65, Q92), but again are not restricted to levee deposits.

At quarry 33, the rootlets are almost certainly in a levee, consisting of 58 in. of fine sandstone interlayered with siltstone laminae. The rootlets may be associated with desiccation cracks (section Q13 and near Q65).

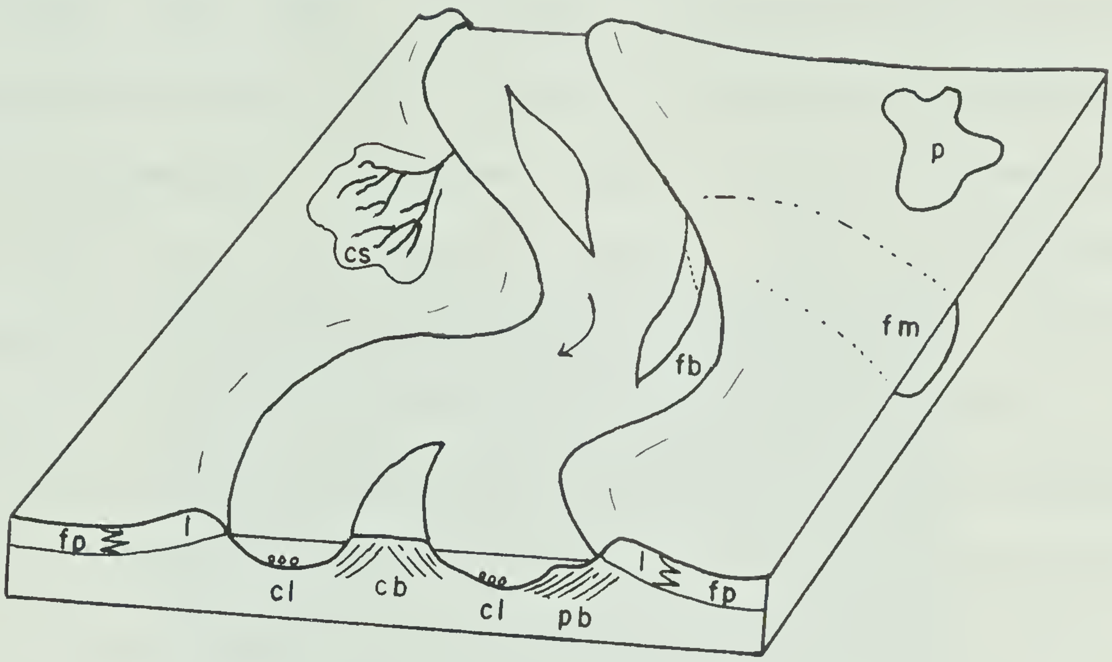
The deposit which Allen (1965) terms swale fill is thought to be applicable to the filling of an abandoned braided channel, and is lithologically similar to the levee deposit, but lacks features of subaerial exposure, such as plant rootlets and desiccation cracks. This interlayered sandstone and siltstone-claystone lithotope is important for the occurrence of fossils, and in several cases it is the fossil itself that aids in determining that the environment represented is subaqueous (channel fill) rather than subaerial (levee). At quarry 86, a hadrosaur was found on its back, apparently indicating that the carcass had been buoyed up in the water by gases held by the visceral cavity. At quarry 88, the excellent preservation of delicate parts of a disarticulated skull of a carnosaur strongly suggests that exposure prior to burial was subaqueous and not subaerial. For these reasons, lithotopes consisting of well stratified silty sandstones, siltstones, silty claystones and claystones from which vertebrate fossils were collected, are interpreted as channel fill deposits.

Floodplain deposits, laid down distal to the channel, constitute the finest fraction of material in transport, and may be thick,with but slight internal lithological contrast. Low areas of the flood basin may be sites of ponds. Allen (1965) noted that floodplain sediments, which are subject to subaerial exposure, may show desiccation cracks, rootlets, autochthonous tree stumps, and drifted plant remains. Evidence of rootlets in claystone is not common, but was noted at

sections Q47 and Q110. Claystones may be rather silty, and some intervals are very rich in allochthonous plant debris. These sediments are interpreted as floodplain sediments. However, the large, low angle cross-strata in claystone, described previously, suggest that bodies of standing water were present, and some of the sediments considered as floodplain materials may actually be of lacustrine origin. Fossils tend to be scarce in this lithotope, and no further evidence was found to aid distinction between floodplains and lakes.

The final overbank deposit to be considered is the crevasse-splay deposit, which results from the breaching of a levee during a flood. The resultant deposit is a relatively thin sandstone, often less than a foot thick within an otherwise normal overbank deposit (Allen, 1965). This may explain the presence of an 18 to 30 in. silty sandstone in an otherwise uninterrupted 20 ft. section of claystone at section Q3. A similar deposit is found at section Q32.

Fig. 9 illustrates the sites of formation of various alluvial sediments. Although all sections measured were specifically located at quarry sites, the large number of sections measured, their wide distribution in the Park (Fig. 1), and their wide stratigraphic range permits them to be considered a fair sample of the sediments of the Oldman Formation as exposed at the Park. Therefore, sedimentological conclusions formulated are regarded as applicable to the Oldman Formation at the Park, not merely to quarry sites.



cb = channel bar deposit

cl = channel-lag deposit

cs = crevasse— splay deposit

fb = channel fill deposit (braided stream)

fm = channel fill deposit (meandering stream)

fp = floodplain deposit

l = levee deposit

p = floodbasin pond

pb = point bar deposit

Fig. 9. Sites of Formation of Alluvial Deposits of a Hypothetical River with both Braids and Meanders

Channel Form

Meandering streams tend to deposit sediments in a characteristic cycle (Allen, 1964, 1965). Overlying an erosional surface cut into fine grained sediment (silt or clay) is a channel sand which may contain a basal conglomerate. The channel sand, of variable thickness, passes upward into a well stratified levee deposit, which in turn gives way to featureless silts and clays of the flood basin. This succession represents the gradual migration of a stream out of the area. A new cycle is initiated by erosion of the top of the previous floodbasin deposit. Such successions are found in the Park. At section Q7, 12 ft. of cross-stratified sandstone passes upward into 15 ft. of fine sandstone interlayered with siltstone with several ironstone horizons, then into 6 ft. of claystone. A new channel sandstone with a basal conglomerate overlies an erosional surface with 3 ft. of relief cut into the claystone. Such cycles are repeated with variation at sections Q17, 21, 33, etc. (Fig. 2). In some cases, claystones are overlain by stratified sandstones (section Q36, Fig. 2). This indicates renewed proximity of a stream during the following cycle, without re-establishment of the channel at the same site.

In contrast to meandering streams, braided streams shift back and forth relatively rapidly, reworking overbank deposits. As a result, channel sediments are dominant, and relatively few topstratum deposits survive intact (Allen, 1965; Moody-Stewart, 1966). In the Park as a whole, channel deposits are dominant, and in individual sections, channel deposits commonly follow one over another (sections Q2, Q5, Q28, etc.). At section Q81, nearly 100 ft. of sandstone is interrupted by only one 2 to 4 ft. interval of claystone (Figs. 2, 10). This is highly

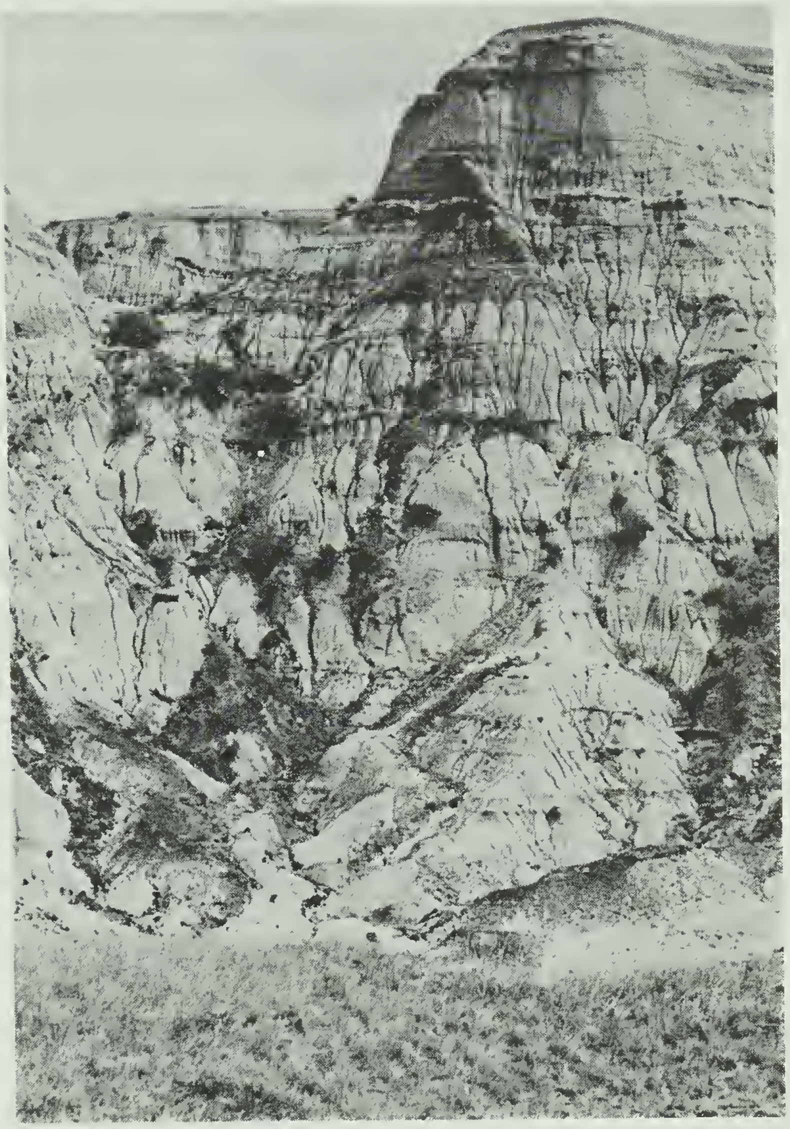


Fig. 10. Thick Channel Sandstones at Quarry 81

suggestive of the persistent channel regimen of the braided stream. Braided streams tend to have broad, shallow channels. Channels in the Oldman Formation are shallow, as indicated by the size of the cross-strata observed in the channel sandstones (sets rarely exceeding 4 ft., and usually less than 2 ft. in thickness).

Thus the sediments of the Oldman Formation show some characteristics of both meandering and braided channels. This is not an extraordinary situation. Leopold and Wolman (1957) have demonstrated that meandering and braided channels are merely end forms in a continuum of channel patterns, and that a given river may have both meandering and straight stretches. Although many factors interact to control channel form, discharge and slope are particularly crucial. Specifically, higher slope and greater discharge favor braiding, lower slope and smaller discharge favor meandering (Leopold and Wolman, 1957).

Descriptions of satisfactory modern analogues of the channel form of the Oldman streams seem to be lacking. This may be, in considerable measure, a result of the specific tectonic conditions prevailing at that time which are not duplicated today (it was the realization of the importance of tectonic conditions on patterns of sedimentation that led Friedman and Johnson (1966) to formulate the concept of a tectonic delta). For example, in the Late Permian, a similar tectonic situation prevailed in the Uralian Geosyncline of Russia, and sediments shed from the rising highlands in the east were carried into the linear, subsiding trough to the west by relatively short (200 to 300 mile long) rivers. Here Olson (1962, p. 127) observed a notable paucity of floodplain sediments.

Irrespective of tectonic conditions, there unquestionably has existed until very recently a strong bias in the study of modern fluvial regimes towards meandering streams in temperate environments, with a corresponding emphasis on similar interpretations for the geological record. Recent studies such as that of Allen (1964) are notable in their escape from the stultifying concept of the Mississippi River type of deposit. Descriptions of streams and stream deposits by Schumm and Lichty (1963) and McKee *et al.* (1967) demonstrate some of the alternatives; these examples show the tremendous effect climate can have on streams.

Rates of Sedimentation

It is important to consider rates of sedimentation in the Oldman Formation. The Oldman and Foremost Formations (Belly River Formation) attain a thickness of about 1000 ft. on the southern plains of Alberta, about the same as the Bearpaw Formation. If a span of three million years, half the interval represented by the Bearpaw, be arbitrarily assigned to the Oldman and Foremost Formations, an average rate of accumulation of sediment of one foot every 3,000 years is obtained. It is apparent that this figure can have little meaning in the interpretation of conditions of burial of large vertebrate fossils. In order to preserve a complete skeleton in full articulation, the time required to lay down the foot or two of sand necessary to bury a carcass almost certainly could not have exceeded a few weeks at the most.

Other features, too, attest to the rapid sedimentation in channels. Jopling (1966) stressed that laminae, especially cross-laminae, of cohesionless sand may form in seconds, minutes or hours rather than

days, weeks or months. The abundant laminae in the Oldman Formation reveal the rapid rate of sedimentation.

One type of deposit that is somewhat difficult to interpret in terms of temporal value is the laminated vegetable unit described on p. 9 . These units might be expected to form under conditions of slow deposition in quiet water; however, they are found in channel sands, which argues against prolonged quiet periods. Jahns (1947) described similar units of laminated vegetable matter from flood deposits of the Connecticut River, which he attributed to the scour of overbank debris in the early stages of rising flood waters. Such features in the Oldman Formation probably represent short time intervals as well. Bank collapse and basal scour, the same processes responsible for the abundant clay pebbles, could have been effective in introducing large quantities of vegetable debris into streams.

While sedimentation was rapid locally, sediments were not synchronously distributed across the whole area at these rates in a layer-cake fashion. Nonetheless, the relatively low rate of net accumulation of sediment of only one foot per 3,000 years, and the braided regimen of the channels, make it seem highly probable that the majority of sedimentary units formed were destroyed by reworking. Clearly, then, the destruction of fossils by reworking was a common event. The fossils preserved are undoubtedly a highly selected sample of the much larger population initially buried.

ENVIRONMENTAL INDICATORS

An important object of this study is an attempt to assess the evidence favoring a relatively proximal or distal marine influence in the Park during the formation of the Oldman deposits. At the outer margin of the Belly River (Judithian) delta in eastern Alberta, continental sediments interfingered with marine shales. Prior to the Oldman continental phase, which left 400 ft. of sediment in southern Alberta, a marine shale (Grizzly Bear member of Shaw and Harding, 1954) penetrated from the east to within 40 to 45 miles of the Park. At this time, brackish water influence may have extended as far west as the Park. Subsequent to this brief incursion, continental conditions of the Oldman prograded eastward and persisted until the Bearpaw Sea swept in, terminating continental deposition. Dinosaurs quarried in the Park occur from about 290 ft. to 86 ft. below the Bearpaw contact (Table II; Sternberg, 1950), and thus 110 to 314 ft. above the Grizzly Bear member, based on the Bearpaw contact as datum. It is within this interval of presumed continental deposits that the search for marine indicators was carried out.

Russell (1940a) presented a faunal list of invertebrates of the Oldman Formation, in which he identified 16 species of freshwater molluscs, mainly uniid pelycepods and gastropods, and three brackish species, including two oysters; the brackish forms are known only from the very top of the formation. Molluscs were rarely seen during the course of field work for this study. A representative collection of molluscs found consists of the uniids _Anadonta prepatorus_ and _Fusconaia? danae_, and the gastropods _Lioplacodes vetula_ and _Viviparus_ cf. _retusus_ (identified by C.R. Stelck), all reasonably regarded as

freshwater species.

The flora of the Oldman Formation is extremely poorly known. Ostrom (1964) presented a list compiled from various sources, from which he concluded that the flora of the Belly River as a whole (localities unspecified) consisted of 70% terrestrial species and 30% aquatic species. During the course of this study, abundant vegetable material was found in the Park, but most of it was transported and too fragmented for identification. Several well preserved plants were identified by W.N. Stewart as _Nymphaeites_, a water lily, and _Equisetum_, a horsetail, both of which are indicative of freshwater conditions. A number of impressions of deciduous leaves were found, but only one was sufficiently complete for identification. It was referred to _Dombeyopsis_, a form genus that, like most Late Cretaceous plants, is of uncertain affinity to any modern plant (W.N. Stewart, pers. comm., 1969). Metasequoian foliage is abundant, but is rarely associated with twigs and is obviously transported. Needle-bearing twigs occasionally found are referred to the form genus _Torreyites_. Cones occasionally found are referrable to _Sequoites dakotensis_ (Bell, 1949). All of the fossil wood so far identified from the Oldman Formation is referred to _Taxodioxylon gypsaceum_ (C.G.K. Ramanujam, pers. comm., 1969); this species shows closer affinities to modern _Sequioa_ (redwood) than to _Taxodium_ (swamp cypress) (Ramanujam and Stewart, 1969). However, the fossil wood was invariably transported; no trunks _in situ_ are known from the Park. In summary, such plants as are known adequately suggest freshwater conditions.

Diverse salamanders in the Oldman Formation (Fox, pers. comm., 1970) are, by modern analogy, strong indicators of freshwater conditions.

The presence of euryhaline Lepisosteus (Darlington, 1957, p. 104) and Myledaphus, a ray, in the Oldman Formation signifies at most only that direct communication with the sea was possible through the river system.

Marked annual rings in the wood from the Oldman Formation (W.N. Stewart, pers. comm., 1969) and concentric growth rings in the vertebrae of Champsosaurus (R.C. Fox, pers. comm., 1969) indicate unequivocably that the climate was seasonal. Seasonal control could have been exercised by an alternation between wet and dry, in the sense of tropical monsoons, or between hot and cold, as in temperate climates. Monsoons result from the differential heating at low latitudes of large, continental land masses and adjacent large areas of sea, with the consequent establishment of seasonally reversing barometric gradients, and involve flow of air across the equator from the horse latitudes of the opposite hemisphere (Miller,1953, p. 135). The Late Cretaceous seaway that bisected the North American continent (see, for instance, Tourtelot and Rye, 1969) would probably have effectively prevented the development of temperature and pressure contrasts between land and sea necessary for monsoons. Also, it is unlikely that in Late Cretaceous times Alberta would have been subject to phenomena characteristic of low latitudes.

If monsoons were therefore improbable, temperature control seems little more probable. Axelrod and Bailey (1968) for instance, presented a strong case for the equability of Late Cretaceous climates in western North America, caused by the moderating influence of the epeiric sea. The Late Cretaceous epeiric seas are known to have been warm. Lowenstam and Epstein (1954) and Lowenstam (1964) reported that although temperatures cooled steadily during the Late Cretaceous, middle

Campanian seas in western Europe were still as warm as 18°C (64°F), and Tourtelot and Rye (1969) determined an apparent temperature of 25°C (77°F) for Lower Maestrichtian sediments in Saskatchewan, although they regarded as probable a significant lightening of the isotopic composition of the waters of the Pierre Sea by the introduction of meteoric water. Estes (1964), in an admirable study of the lower vertebrates of the Upper Maestrichtian Lance Formation of Wyoming, argued for a subtropical climate for this biota. He did so on the basis of the diverse fauna of fish, amphibians and reptiles, most of which have modern relatives in the tropics or subtropics, but which have peripheral temperate distributions as well. Irrespective of the specific modern affinities of this fauna, the diversity of the various groups suggests, by modern analogy, a subtropical or tropical climate (Darlington, 1957). Estes corroborated this opinion with data from Dorf's (1942) study of the flora of the Lance Formation. Estes believed the ratio of entire-margined to non-entire-margined leaves noted by Dorf, 54% to 46%, to indicate a subtropical rather than a warm temperate climate.

The climate that pertained to the Oldman Formation should have been warmer and more unequivocably subtropical than that of the somewhat later Lance Formation. However, such plants as have so far been identified from the Park are by no means indicative of a subtropical climate, and are thought by Stewart (pers. comm., 1969) to be suggestive of a warm temperate climate instead. As _Nymphaeites_ and _Equisetum_ are equivocal as climatic indicators (Dorf, 1942), the taxodiaceous wood is the best botanic indicator of climates available at present for the Oldman Formation. Taxodiaceous woods today enjoy a warm temperate

[illegible]

distribution, although Estes (1964, p.150) deprecated this point in making his interpretations.

Of great interest in this regard is a recent statement by Axelrod and Bailey (1969, p. 181) on the importance of equability:

> "The pseudo-tropical nature of highly equable thermal regimes favors luxuriant vegetation, as seen in the presence of leaves of tropical to subtropical genera that have entire margins, though of moderate to small size. Clearly, it is a lack of frost--not tropical levels of heat--that is to be associated with such leaf characteristics. And if serrated leaves and needle leaves are also a part of the assemblage, the evidence is even stronger for a highly equable environment rather than one of tropical warmth.... (Such mixed assemblages) are so common as to suggest that climates of high equability were more widely distributed than they are today, an interpretation that differs radically from a prevailing mode of thought which readily assigns a tropical or subtropical designation to any Cretaceous or Tertiary flora in which entire-margined leaves are common."

On this basis, an equable temperate climate can be postulated for the Oldman Formation. The equable frost-free nature of the climate would support diverse poikilotherms, while the temperate nature would satisfy the botanic evidence. The equability of the climate resulted from the proximity of the warm epeiric seas, which would have imparted an oceanic climate to the adjacent lowlands. The seasonality of the climate probably derived from seasonally distributed rainfall. There is no evidence to suggest that water was in periodic short supply; the rain would not have been monsoonal, only seasonal.

It was quite correctly pointed out by Axelrod and Bailey (1969) that such terms as warm temperate and subtropical are imprecise and rarely defined. Standard texts of physical geography (i.e., Trewartha et al., 1968) do in fact define their terms, by employing a scheme (much modified from that pioneered by Köppen) based on monthly average temperatures. Thus, the tropics are frost free, with average

temperatures of all months above 65°F (18°C); subtropical climates are subject to frost, but have at least eight months of the year with average temperatures above 50°F (10°C), and one cool month below 65°F (18°C); and temperate climates have 4 to 8 months above 50°F (10°C). By this designation, southeastern United States, including North Carolina, Tennessee and Arkansas, and also much of California, are subtropical. This clearly contradicts the usage of botanists, who describe Taxodium and Sequoia, living today in the Southeast and California, respectively, as temperate plants. Intentions of paleobotanists are indicated, but not clearly defined, by Dorf (1942, Table 2), Bailey (1964, p. 535) and Axelrod and Bailey (1969, fig.1).

Thus to a considerable extent, the whole discussion as to whether the Oldman climate was warm temperate or subtropical is specious. The comparison of the Lancian climate to that of the south Atlantic and Gulf coastal plains suggested by Estes seems eminently applicable to the Oldman climate as well. For instance, the remains of turtles, crocodiles and garpikes (Lepisosteus), the animals upon which Weigelt (1927) carried out his taphonomic observations at Smithers Lake, Texas, very near the Gulf of Mexico, are among the commonest of fossils from the Oldman Formation. The disagreement with Estes' interpretation of the climate expressed in this paper is therefore only semantic, based on conflicting definitions of the terms, subtropical and temperate.

Eleven samples of claystone were processed and examined in an attempt to determine if Foraminifera or ostracodes were present, as such fossils could potentially yield very useful information concerning the proximity of the sea. Two samples, one from 165 ft. below the Bearpaw

Formation (section Q65, Fig. 1, 2), the other 245 ft. below (section Q32), yielded a sparse return of four agglutinated Foraminifera, two of which were referred to ?Trochammina, and one each to ?Saccammina and Haplophragmoides (identified by G. Sutherland). Russell and Chamney (1967) record the presence of Haplophragmoides in the basal part of the Edmonton Formation, and also higher up. Haplophragmoides and Trochammina have been reported in the upper part of the estuary of the James River of Virginia, where salinities range from 0.5 to 14 parts per thousand (Nichols and Norton, 1969), and Trochammina has been reported from ponds of potable water in the Algerian dessert (Loeblich and Tappan, 1964, p. 129). Given the low rate of occurrence of Foraminifera in the samples examined from the Park, their poor condition, and the notable tolerance of at least two of the genera for conditions of reduced salinity, the occurrence of Foraminifera as presently known does not require proximal marine influence; such few as were found could easily have been transported from brackish regions by a euryhaline fish or other agent of transport. Negative evidence is, of course, always vulnerable and further research could turn up better material, although the probability does not seem great.

Two geological features noted have possible significance. At section Q7, 245 ft. below the Bearpaw contact, a small set of cross-strata was noted with foresets defined by laminae of clay (Fig. 6). Land and Hoyt (1966) described similar cross-strata from a tidal estuary; the clay laminae were laid down during daily periods of non-flow controlled by the tide. The presence of this feature in the Oldman Formation does not, of course, necessarily indicate tidal conditions, but it does indicate a short term alternation between conditions of flowing and still water,

for which tidal control is a ready explanation. Near quarry 101, about 150 ft. below the Bearpaw contact, a small piece of fossil wood was found encrusted with chalcedony in a cubic habit, possibly pseudomorphic after halite. If the interpretation is correct, saline conditions are indicated.

Occasionally pieces of fossil wood that have been attacked by boring organisms are found in the Park (R.C. Fox, pers. comm., 1969). Boring organisms are generally but not exclusively marine; non-marine borers include a gastropod-boring annelid from Southeast Asia and lithophagous snails from the Swiss Alps and British Honduras (Boekschoten, 1966; Craig, 1967). Therefore, the presence of bored wood probably does not require marine influence.

In summary, the balance of evidence seems to favor rather strongly the conclusion that conditions in the Park were fresh, and the climate warm temperate and equable. Evidence observed to the contrary was infrequent and equivocal.

TAPHONOMY

Systematic paleontology, concerned with anatomical aspects of organisms as the key to establishing phyletic relationships of fossils, has been studied for more than a century and a half. In contrast, interest in what Brouwer (1967) termed general paleontology (including ecological, zoogeographic, stratigraphic and sedimentological aspects of paleontology) has been slow to develop in Europe, and slower still in North America. Weigelt (1929) published in German a study of the remains of modern vertebrates, notably cows, fish, crocodiles and turtles of the Gulf Coast of Texas. He drew attention to parallels between the condition of the corpses of modern animals and the condition of animals in the fossil record. Thus he established the discipline of biostratonomy, the science of the embedding of organisms in the rocks, concerned with the fate of animals from the onset of the death struggle to final burial and fossilization (Müller, 1951). Regrettably, there has been little subsequent work on the problems of death, decay and transport of vertebrates (Payne, 1965; Clark _et al_., 1967; Voorhies, 1969), and our knowledge of the fate of organisms after death remains embryonic.

Efremov, a Russian, published in a somewhat obscure American journal in 1940 an important article (his only attempt at publishing in English) announcing "Taphonomy: New Branch of Paleontology". Direct quotation of some of his words is appropriate (p. 85):

> "The chief problem of this branch of science is the study of the transition (in all its details) of animal remains from the biosphere into the lithosphere....
> "The passage from the biosphere to the lithosphere occurs as a result of many interlaced geological phenomena.

> That is why, when this process is analyzed, the geological phenomena must be analyzed in the same measure as the biological ones.
>
> "In the indissoluble unity of geological-biological analysis lies the key....."

Taphonomy is, then, a broad field of integrated study of fossil beds from both biological and geological points of view in order to interpret the occurrence of fossils. A thanatocoenose reflects not so much the fauna of the source area as the unique combination of geological and biological processes that lead to the creation, preservation and ultimate exposure of the fossil bed (Efremov, 1953, p. 94); taphonomy seeks to evaluate the effects of these processes on given fossil beds. This is not paleoecology, which has as its goal the reconstruction of ancient living communities. However, taphonomic considerations should be prerequisite for ecological studies, and taphonomic (biostratonimic) techniques are familiar tools for many invertebrate paleoecologists (Ager, 1963). Efremov (1940) stated that taphonomy plus functional morphology leads to paleoecology; neglecting taphonomy leads to error in paleoecology.

Müller (1951, 1963) presented a highly detailed study of the fundamentals of biostratonomy, including consideration of the causes of death, course of decay and means of transport and burial. His numerous examples of both vertebrates and invertebrates offer an excellent review of some superb European work, much of it concerned with marine organisms.

Olson (1958, 1962) has promoted Efremov's work in North America, and much of his own work has shown the fruitful application of taphonomic techniques (Olson, 1952, 1958, 1962); he has been more interested in faunal paleoecology _sensu stricto_ than in the fate of

individual animals. A classic work in taphonomy is Zangerl and Richardson's (1963) monograph on the paleoecological history of two fish-bearing Pennsylvanian black shales; this is a model of extremely detailed biostratonomy of a very limited area. They were fortunate in that the shale was a very low energy deposit, whose fissile nature permitted bulk removal to a laboratory for study; such conditions are very uncommon in continental clastic deposits. Clark et al (1967) considered sedimentation in the Oligocene of South Dakota, and a few useful taphonomic insights resulted.

Voorhies (1969) presented the first North American work with a declared object of taphonomic enquiry. This is a highly interesting investigation of a Lower Pliocene bonebed, in which he collected, measured and mapped over 20,000 bones, all but a few disarticulated, from a bonebed 32 ft. long and 4 ft. deep. From the data he collected, he was able to reconstruct the environment of deposition, mode of formation of the deposit, and population structure of the animals found. Of great importance is his report on flume experiments on disarticulated mammalian bones.

Taphonomy of the Oldman Formation, Steveville, Alberta

Dinosaur Provincial Park includes 15,000 acres of badlands adjacent to an 18 mile length of the Red Deer River. Exposures are excellent, and bone is locally abundant. An investigation of bonebeds in the manner of Voorhies (1969) would have been appropriate, and in fact should be done. Instead, however, the approach taken in the project was to take advantage of the results of C.M. Sternberg's efforts in 1936 to relocate the exact sites of quarries from which the great

collectors had removed specimens over the previous 25 years (Sternberg, 1950). Thus biostratonomic data were obtained for specimens already described and collected; normally, if such are not made at the time of collection, the opportunity is lost forever.

That the fossils represented by the quarries located during field work for this project constitute a biased sample of the reptilian fauna of the Park is undoubted. For instance, Russell (1967a) suggested that the actual number of hadrosaurs collected should possibly be doubled to obtain a representation of their true abundance relative to other dinosaurs. Collectors, especially in the early days, were primarily interested in obtaining exhibition-quality specimens. However, the list of specimens collected from the quarries (Table II; Sternberg, 1950) shows a fairly complete spectrum of types of preservation, ranging from complete skeletons (quarries 1, 36, 43, etc.) to single bones (quarries 7, 67). Conclusions concerning the geological occurrence of fossils formulated by observations of quarries are consistent with the occurrence of bone found in the Park today. In spite of the recognized biases, it is felt that the conclusions presented validly reflect the taphonomic occurrence of bone in the whole region studied.

Stratigraphic Distribution of Fossils

Quarries are distributed from an elevation of 2126 ft. above sea level (quarry 26) to 2328 ft. (quarry 106), an interval of about 202 ft. (Table II; Sternberg, 1950). Quarry 106 lies about 60 ft. below the marine Bearpaw Formation, as located by quarry 109 (Sternberg, 1950). However, the vertical distribution does not equal the stratigraphic distribution, because the beds are not flat-lying, having

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[illegible]

[illegible]

TABLE II SUMMARY OF DATA ON QUARRY FOSSILS

List of Abbreviations

AMNH: American Museum of Natural History
artic.: articulated
BB: Barnum Brown
CHS: C.H. Sternberg
clay: claystone
CMS: C.M. Sternberg
corac.: coracoid
disartic.: disarticulated
exc.: except
fib.: fibula
frag.: fragments
GFS: G.F. Sternberg
hum.: humerus
incl.: including
intrafm. congl.: intraformational conglomerate
l.: left
lam. veg.: laminated vegetable unit
LS: Levi Sternberg
max.: maxilla
N: quarry not found
NMC: National Museum of Canada
pt.: part
Q: quarry
rad.: radius
ROM: Royal Ontario Museum
rt.: right
scap.: scapula
scatt.: scattered
sed.: sediment
silt: siltstone
strat. posit.: stratigraphic position
ss.: sandstone
tib.: tibia
v.: very
veg.: vegetable
vert.: vertebra
WAP: W.A. Parks
WEC: W.E. Cutler
xs bd: cross-bed
Y: quarry found

Table on following pages

TABLE II SUMMARY OF DATA ON QUARRY FOSSILS

Quarry No.	Specimen	Collector Date	Condition	Preservation Class (see Table VI)	Elevation	Strat. Posit. below Bearpaw	Quarry found? axis	Lithology (see Table II)	Position in Section	Interpreted Environment	Source
1	Corythosaurus casuarius type	BB 1912	complete exc. end of tail, left manus N.B. integument	A	2133′	239′	Y 110°	clean white ss.; minor veg. above I	4' in $6\frac{1}{2}$' ss.; above: clay; 20' clay-silt below	channel	Lull & Wright, 1942
2	Euoplocephalus tutus	GFS 1921	skull, fairly complete skeleton	G	2236′	135′	Y	clean ss.; minor veg. I	8' in ss.; above: v. thick clays; 4' clay balls below Q	channel	GFS, field notes, 1921
3	Stegoceras validus	GFS 1921	skull, jaws, ribs, gastralia, pelvis, rt. femur, left leg, no feet, a few caudal vert., scattered	D	2189′	173′	Y	xs bd ss. abund. veg. II	3' ss. below - 40' clay below that; 18' ss. above xs bds., veg. low, fining top half	slow channel	Gilmore, 1924
4	Monoclonius flexus type	BB 1912	skull	J	2140′	232′	Y	clean xs bd ss. I	13' thick, Q at 3'; 9' clay above	channel	Lull, 1933
5	Centrosaurus	WEC	skull	J	2194′	173′	Y	clean xs bd ss. veg. layers local I	at 9' in 15' ss. with xs veg.; above: small channel cut, filled; below: 20' clay	channel	Sternberg, 1950 (map)
7	armoured dinosaur	BB 1913	sacrum	K	2139′	228′	Y	xs bd ss. clay-sand interface I	9' channel ss. cut into 6' clay; below: 16' overbank sed.; below: channel ss. 12'	bottom of channel on clay	photo 28694 AMNH, specimen AMNH 5403
8	hadrosaur lost at sea	CHS 1916	complete	A	2215′	143′	N				Sternberg, 1917
9	Chasmosaurus belli	LS 1926	complete	A	2237′	118′	Y 035°	ss. with minor veg. I	17' ss. above, 4' clay, 10' ss., 2' veg. clay	channel	Lull, 1933
10	hadrosaur lost at sea	CHS 1916	headless	F	2197′	160′	N				Sternberg, 1917
11	Aspiderites	LS 1934	complete with jaws and legs	A	2225′	91′	N				Sternberg, 1950 (map)
12	Struthiomimus samueli type	LS 1926	head, neck, girdle, arms	L	2239′	118′	Y	ss. with xs veg. II	14' ss. with 25% silty layers, 19' clay below	channel bottom	Parks, 1928
13	Lambeosaurus	LS 1926	skull	J	2211′	149′	Y	ss. with many clay balls III	at $2\frac{1}{2}$' in $7\frac{1}{2}$' ss. with clay balls; below: clean ss.; above: xs bd ss.	shallow channel	Sternberg, 1950 (map)
14	Aspiderites	LS 1934	with head	A	2225′	135′	N				
15	hooded hadrosaur	LS 1934	hind leg and foot	L	2244′	121′	Y 070°	thin ss. with clay balls III	12-25' channel ss. below; 20' mixed sed. above	at top of channel	Sternberg, 1950 (map)
16	Macrophalangia canadensis	CMS 1928	artic. foot, rest eroded	L	2226′	103′	Y	ss. with 4' xs bd I	3' channel ss. below; 6' channel ss. above; 3' mixed levee above	in channel	Sternberg, 1932 NMC photo 71101
17	Corythosaurus bicristatus type	LS 1933	skull with jaws	H	2141′	231′	Y	white fine ss. I	2' same below; 15' same above; clay above that	channel	Parks, 1935

Table II. cont.

Quarry No.	Specimen	Collector Date	Condition Preservation Class (see Table VI)		Elevation	Strat. Posit. below Bearpaw	Quarry found? axis	Lithology (see Table II)		Position in Section	Interpreted Environment	Source
18	Struthiomimus	LS 1934	pelvis, hind legs, feet	K	2139'	233'	Y 020	xs bd ss. with clay-balls	III	8' clean xs bd ss. below; 10' xs veg ss. above	channel	Sternberg, 1950 (map)
19	Corythosaurus brevicristatus type	LS 1934	skull with jaws	H	2140'	232'	Y	thin xs bd ss. with veg	II	below: channel ss. 10'; above: 7' channel ss. with veg.; 5' ss. fining to clay at top	channel	Parks, 1935
20	hooded hadrosaur	LS 1933	pelvis, hind limbs, tail	K	2149'	223'	Y 055	ss. and veg.	II	at 9' in 15' of veg. ss.; below: v. clean xs bd ss.; above: clay	channel, lower energy	Sternberg, 1950 (map)
21	Gorgosaurus	LS 1933	complete exc. dorsal and cervical vertebrae, occiput	A	2132'	240'	Y 025	ss. with some clay	IV	above: 10' mixed ss., silt, clay	channel fill	ROM display
22	Gorgosaurus	LS 1934	parts of a scattered skull	I	2134'	232'	Y	clean ss.	I	below: 4½' mixed ss.-clay; above: clay 5½'	channel fill	Sternberg, 1950 (map)
23	Corythosaurus casuarius	LS 1934	skull	I	2157'	209'	N					Sternberg, 1950 (map) Parks, 1935
24	Chasmosaurus brevirostris type	LS 1926	skull and pt. of skeleton	K	2243'	129'	Y	ss. with veg. scatt. small bone clayballs	V	8' xs bd channel ss. below; in 2' ss. clay; 4' channel ss. above	top of active channel	Lull, 1933
25	crocodile	CMS 1928	pelvis, legs, tail; rest eroded	K	2142'	220'	N					NMC photo 71100
26	Gryposaurus	LS 1934	skull	I	2126'	234'	Y	xs bd ss.	I	at bottom of 20' channel ss. with clayballs	channel	Sternberg, 1950 (map)
27	Gryposaurus notabilis type	CHS 1913	complete exc. 1 leg, arms, pt. of tail	A	2161'	199'	Y	xs bd ss.	I	at 31' in 35' channel ss.	channel (towards top)	Lambe, 1914
28	Tetragonosaurus cranibrevis type	CMS 1928	skull + 7 cervicals; skeleton scattered, eroded, lost	C	2217'	143'	Y	clayball ss.	III	above: 4' clean fine ss.; below: 8½' channel ss.	channel	Sternberg, field notes, 1928 Lull & Wright, 1942
29	crocodile	CMS 1928	skull	I	2199'	163'	N					Sternberg, 1950 (map)
30	Lambeosaurus clavinitialis type	CMS 1928	complete exc. left Q, dorsal vert., left cervical + anterior ribs, left ilium: erosion; some drifting	B	2216'	146'	Y	ss. with clay, veg.	VI	below: 20" clayballs, 13' channel ss.; above: 6' veg. rich xs bd ss.; 4' levee	upper channel	Sternberg, field notes, 1928 Lull & Wright, 1942
31	Chasmosaurus russelli	CMS 1928	probably complete but erosion scattered; skull, jaws, scap., carac., hum., tib., fib.	A	2198'	164'	Y	xs bd ss.	I	below: clay; above: 15' channel ss.	base of channel	Sternberg, field notes, 1928 Sternberg, 1940
32	Corythosaurus frontalis type	LS 1934	skull and jaws	H	2206'	156'	Y	fine ss.	I	2' in 8½' fine ss., silt near base; below: 6' coarse xs bd ss., some lam veg.	slower channel	Parks, 1935
33	Centrosaurus	LS 1926	skull	I	2218'	144'	Y	ss. or ss. with rootlets?	I	below: channel ss.; above: 13' levee sed.	channel fill	Sternberg, 1950 (map)

Table II. cont.

Quarry No.	Specimen	Collector Date	Condition Preservation Class (see Table VI)	Elevation	Strat. Posit. below Bearpaw	Quarry found? axis	Lithology (see Table II)	Position in Section	Interpreted Environment	Source
34	hadrosaur	CHS 1915	skeleton less skull E	2175'	190'	Y 135°	ss. fining to clay I	at 20" in 30" of fining ss.; above: 2' clay and silt, then clay	top of channel	Sternberg, 1950 (map)
35	Lambeosaurus	CHS 1913	skeleton lacks head, shoulders E	2198'	168'	Y 025°	brown fine ss., with clayballs, veg. & clay V	below: 2' same, then channel ss.; above: 1" ss. and veg., then 15' clay	channel fill	photo 25429, NMC
36	Gorgosaurus libratus type	CHS 1913	complete exc. distal end of tail A	2248'	114'	Y 005°	ss. with veg., clay and clayballs V	below Q, 6' silt, $2\frac{1}{2}$' silt, ss., 25' clay; above: alternating brown and white ss.	low energy channel	Lambe, 1914 b
37	Chasmosaurus belli	CHS 1913	complete exc. erosion: pt. of tail, left tib.-fib., ulna; rt. rad., ulna A	2270'	95'	Y 155°	ss. interlayered with silt, clay IV	base of 12' interlayered sed. with 20% silt, clay	channel fill	Sternberg, 1927
38	Champsosaurus	LS 1930	snout, column, pelvis, gastrolia, prox. femoral pts.; skull, girdle + arms, most of legs gone: erosion A	2242'	132'	Y	ss. with clay-balls, much veg. V	below: 8' silt, clay, interlayered with 10% ss.; 2-5' clay over	channel fill	Parks, 1933
39	Prosaurolophus	LS 1930	skull, right and left front legs, feet K	2265'	109'	Y 015°	fine ss. I	below: 7' silt with some ss., 18' ss.; above: 16' ss.	channel base	Sternberg, 1950 (map) ROM catalogue
40	hooded hadrosaur	CMS 1919	posterior half of skeleton: anterior washed away K	2271'	95'	Y 165°	v. clean fine ss. I	at 6' in 8' clean fine ss.; above: 4' clay, 2' ss., 4' clay, 30' ss.	channel	Sternberg, field notes, 1919 photo 46579, NMC
41	Chasmosaurus belli	CMS 1919	skull less jaws, upside down I	2252'	150'	Y	ss. I	6" below: clay; above: 15' channel ss.	bottom of channel	Sternberg, 1950 (map) photo 46576, NMC
42	Centrosaurus apertus	CMS 1919	skull less snout and part of crest: on side I	2250'	152'	Y	ss. I	above: intrafm. conglom. 20' xs bd ss. below: clay 13'	bottom of channel	Lull, 1933 photo 46574, NMC
43	Monoclonius nasicornis type	BB 1914	very complete A	2262'	145'	Y	ss. with some veg. II	at 2' in 16' xs bd ss. with veg., clayballs; below: clay	channel	Lull, 1933
44	Corythosaurus	GFS 1921	headless; forelimbs damaged; no neck; l. humerus, no scap., rad., ulna, right ilium, tib. fib. gone; rest present E	2265'	142'	Y 085°	ss. with veg. II	above: 6' ss. with lam. veg., minor clay, then 10' channel ss.; below: $4\frac{1}{2}$' lam. veg. ss. with clay, 7' channel ss	low energy channel	Sternberg, field notes, 1921
45	armoured dinosaur	BB 1915		2260'	152'	Y	ss. I	at 9' in 20' or more channel ss.	channel	Sternberg, 1950 (map)
46	Lambeosaurus magnicristatum type	CMS 1919	lacks left manus + pt. of foreorm, rt. forelimb rt. ribs, distal caudals; erosion on arm; ilium, end of tail scattered B	2325'	87'	Y 025°	ss. with minor veg. I	at 2' in 3' veg.-free ss. in 20' of veg.-rich ss.	low energy channel	Lull & Wright, 1942 Sternberg, field notes, 1919
47	Corythosaurus intermedius	CMS 1917	from 5th caudal forward; rt. limb drifted to left side, foot scattered; rt. ribs + front limb gone; left humerus drifted B	2308'	119'	Y	ss. with veg. & clayballs V	above: veg.-rich channel ss.; below: 3' ss. silt, clay; 25' silt, clay	base of channel	Sternberg, field notes, 1917
48	Gorgosaurus	GFS 1921	much of skeleton, but at least partly scattered (i.e. thorax) B	2163'	259'	Y	clean xs bd ss. I	at 8' in 45' channel ss.	channel	Sternberg, field notes, 1921
49	Chasmosaurus	LS 1930	skull I	2308'	109'	N				Sternberg, 1950 (map)

Table II. cont.

Quarry No.	Specimen	Collector Date	Condition Preservation Class (see Table VI)		Elevation	Strat. Posit. below Bearpaw	Quarry found? axis	Lithology (see Table II)	Position in Section	Interpreted Environment	Source
50	Gorgosaurus	CMS 1917	pelvis, left femur, pt. of rt.; 2 tibiae, 6 metatarsals, 12 phalanges; 8 caudal vert. with chevrons	G	2326'	101'	Y	ss. with some veg. II	12' ss. channel above; 6-9' clay below	base of channel	Sternberg, field notes, 1917
52	Corythosaurus	CHS 1917	complete exc. 1 tibia, 1 arm	A	2186'	241'	Y	clean xs bd ss. I	$4\frac{1}{2}$' in 37' channel ss.; below: 8' clay	channel	Lull & Wright, 1942
54	Gorgosaurus sternberg	CHS 1917	complete	A	2193'	234'	Y 035°	clean fine ss. I	at base of 10' of channel ss.	channel	Matthew& Brown, 1923
55	hooded hadrosaur	LS 1921	pelvis, hindlimbs, tail	K	2208'	219'	Y 120°	clean xs bd ss. I	at 9' in 16' xs bd ss. with minor silty layers	channel	Sternberg, 1950 (map)
56	hooded hadrosaur	CMS 1936	skull (not collected)	I	2187'	237'	N				
57	Gorgosaurus	BB 1913	skull and jaws plus a few bones of skeleton	D	2183'	242'	N			channel	Matthew& Brown, 1923 photo 19440, AMNH
58	Gryposaurus sp. (=Brachylophosaurus)	CMS 1936	skeleton from mid-thorax forward; 12 dorsal vert. artic.; cervicals, forelimbs, ribs, skull, scattered; skull partly artic.	F	2133'	276'	N				Sternberg, 1953
59	Gorgosaurus	BB 1913	left max., left tibia, metatarsal + phalanges + femur + frag. N.B. also left dentary; scattered	D	2152'	251'	Y 005°	clean ss. I	at 2' in 10' ss.	channel	Matthew& Brown, 1923 photo 19449, AMNH
60	armoured dinosaur	BB 1913	left scapula only	J	2149'	253'	Y 170	clean ss. I	at 10' in 19' ss.	channel	Coombs, 1969, pers.com. Sternberg, 1950 (map)
62	hooded hadrosaur	CMS 1936	scattered skull plus scap., ribs, vertebrae	D	2216'	193'	Y	clean plane laminated ss. I	at 3' in 8' of same; clay above and below	channel	Sternberg, field notes, 1936
64	Tetragonosaurus praeceps	LS 1930	skull, artic. column to sacrum; rt. scap., rib fragments + jaws	F	2189'	225'	N				Lull & Wright, 1942
65	Centrosaurus longirostris	CMS 1917	skull, jaws, 1 ilium, 1 femur, pts. of other, limbs, some phalanges, 2 vertebrae	D	2172'	245'	Y	clean ss., minor coal & clayballs I	base of 8' channel ss.; below: clay	channel	Sternberg, field notes, 1917 Sternberg, 1940
66	Centrosaurus dawsoni	CMS 1917	skull less lower jaws	I	2220'	197'	Y	clean xs bd ss. I	at 6' in 27' channel ss.	channel	Sternberg, 1950 (map) Sternberg, field notes, 1917
67	Caenagnathus collinsi type	CMS 1936	jaws only, fused	J	2181'	243'	N				Sternberg, 1940
68	Corythosaurus intermedius	CMS 1919	skull + jaws, ribs + column, rt. forelimb, hind legs + pelvis; somewhat scattered	B	2254'	177'	Y 85°	xs bd ss., some veg., clayballs V	13' in 28' channel ss.	channel	Lull & Wright, 1942 Sternberg, fieldnotes, 1919 photo 46585, NMC
69	Panoplosaurus mirus type	CMS 1917	skull, neck, some dorsal vert., ribs (anterior), sacrum, fragments of pelvis, some limb material; partially scattered	B	2263'	169'	Y 145°	ss. with some veg. & clay VI	at 5' in 20' of same	slow channel	Lambe, 1920 Sternberg, 1921, 1929

Table II. cont.

Quarry No.	Specimen	Collector Date	Condition Preservation Class (see Table VI)	Elevation	Strat. Posit. below Bearpaw	Quarry found? axis	Lithology (see Table II)	Position in Section	Interpreted Environment	Source
70	horned dinosaur	CMS 1919	pt. of skull, crest lost; pectoral girdle, artic. left forelimb, tib., fib., lost; most of skeleton weathered away F	2270'	160'	Y	fine ss. with silt, clay IV	at 2' in 4' of fine sed., above: 7' channel ss.; below: 35' channel ss.	channel fill	Sternberg, field notes, 1919
71	Lambeosaurus clavinitialis	CMS 1919	skull; dentaries, one max., jugals, scattered H	2265'	165'	Y	ss. with some veg. and clay I	below: 17' ss. with clayballs above: 12' channel ss. with some veg.	channel	Sternberg, field notes, 1919 Lull & Wright, 1942 Sternberg, 1950 (map)
72	Corythosaurus excavatus	CMS 1919	scattered skull + skeleton; apparently most was present C	2278'	150'	Y	ss. with clayballs III	at bottom of 4' ss. with clayballs; above: 9' channel ss; below: alternating clay & fine ss.	basal channel above levee	Sternberg, field notes, 1919 Sternberg, 1950 (map)
73	Edmontonia rugosidens	LS 1935	skull, 1 jaw, 8 vert., 24 ribs, 6 sternals, rt. coracoid, left ulna, 2 humeri, 3 phalanges, 300 plates K	2264'	166'	Y	clean ss. I	at 20' in 35' ss. with some veg. & clayballs	channel	Russell, 1940
74	Centrosaurus	CHS 1917	skull and jaws H	2263'	167'	Y	ss. I	at 22' in 32' ss.	channel	Sternberg, 1950 (map)
76	? Paleoscincus	CHS 1917	complete from mid thorax forward K	2233'	194'	Y	ss. with veg. throughout II	at 3' in 4' ss.; below: silty ss.; above: ss. with clayballs	channel	AMNH display
77	Eoceratops sp.	GFS 1920	skull; much of postcranial skeleton present but scattered B	2270'	154'	Y	ss. I	at 16' in 35' xs bd ss. with veg. & clayballs	channel	Sternberg, field notes, 1920
79	Prosaurolophus maximus	LS 1921	2 skeletons: 1 almost complete skeleton with skull; 1 mounted A	2279'	145'	Y				Sternberg, 1950 (map) ROM catalogue
81	Lambeosaurus	CHS 1914	pt. of skull I	2234'	183'	Y	ss. xs bd with lam. veg. II	at 5' in thick channel section	channel	Sternberg, 1950 (map)
82	Prosaurolophus maximus	CHS 1914	skull; scattered postcranium uncollected, incl. sacrum, limbs, ribs, vert. C	2272'	146'	Y	ss. with clayballs III	at base of thick xs bd ss. with some lam. veg.	channel	Sternberg, 1950 (map) field observation, 1968
83	Chasmosaurus belli	CHS 1914	complete exc. both radii, ulnae; rt. leg, distal left leg, posterior pelvis + tail: erosion A	2214'	203'	Y	xs bd ss. I	at 7' in 14' clean xs bd ss.	channel	Sternberg, 1927
84	Corythosaurus casuarius	BB 1914	complete exc. end of tail, most of left hand, pt. of right hand A	2185'	132'	Y 115°	clean ss. I	at $1\frac{1}{2}$' in 5' fining sequence; above: mixed ss., silt, clay; below: 4' ss. with ripple drift, small xs bds	declining channel	Lull & Wright, 1942
85	Corythosaurus intermedius	LS 1920	skull with jaws H	2244'	173'	Y	fine ss. with clayballs III	21' in 23' channel ss.; above: 3' silt, silt-clay; then 9' channel ss. again	top of channel	Parks, 1923
86	Tetragonosaurus sp.	LS 1920 CMS 1936	2 good skeletons LS.; A CMS 1 good: feet scattered; neck twisted from body; 1 eroded: complete before B	2179'	233'	Y	fine ss. I	above: 28' interlayered clay, ss. below: clay	channel fill	Sternberg, field notes, 1936
87	Parasaurolophus walkeri	LS 1920	complete to pelvis, lacks tail, legs, but has l. femur F	2178'	234'	Y 055°	ss. I	1' in 5' upward fining ss.; above: 9' clay, 8' ss.	slowing channel	Lull & Wright, 1942
88	Gorgosaurus (=Daspletosaurus type)	CMS 1921	from 12th caudal forward; left ilium drifted; l. side of skull disartic.; l. ribs scattered, as are gastralia + chevrons; delicate preservation B	2152'	260'	Y 160°	ss. with silt IV	3' above Q: 13' ss. with silt	channel fill	Sternberg, field notes, 1921

Table II. cont.

Quarry No.	Specimen	Collector Date	Condition Preservation Class (see Table VI)	Elevation	Strat. Posit. below Bearpaw	Quarry found ? axis	Lithology (see Table II)	Position in Section	Interpreted Environment	Source
92	Lambeosaurus	LS 1919	incomplete skeleton K	2293′	129′	Y	ss. I	8' ss. above; 10' ss. below; some silt	channel	Russell, 1965
93	Dyoplosaurus acutasquameus type	LS 1919	tail club to sacrum; rib, tooth, and skull fragments G	2193′	227′	Y	xs bd fine ss. I	at 5' in 23' ss.	channel	Parks, 1924
94	Centrosaurus apertus	WAP 1919	skull + jaws, 17 vert., both scap., corac., humeri, l. distal arm + manus, sternal bones; rest eroded away;probably was complete A	2198′	222′	Y	xs bd ss. I	above: 20' xs bd ss.; below: 5' clay	base of channel	Parks, 1921
95	Centrosaurus	LS 1930	skull and pt. of skeleton	2201′	221′	Y	ss. with many clayballs III	at 2' in 13' ss. with clayballs; below: clay	low in channel	
96	Corythosaurus intermedius	LS 1919	bones of skull scattered in ss–jaws present; skeleton badly eroded F	2224′	205′	Y 065°	xs bd ss. I	at 28' in 50' ss. with some veg., clayballs; lam. silt at top	channel	Parks, 1923
97	Corythosaurus intermedius	WAP 1919	skull I	2235′	197′	Y	clean ss. I	at 15' in 40' ss.; rootlets 2' below Q; silt upper 10'	channel (shallow)	Sternberg, 1950 (map)
98	small hadrosaur	CMS 1921	head + neck eroded; left ilium + leg, drifted, lost; rest present F	2140′	272′	Y	xs bd ss. with veg. II	at $1\frac{1}{2}$' in 14' channel ss.	base of channel	Sternberg, field notes, 1921
99	hooded hadrosaur	LS 1927	no head E	2261′	151′	N				Sternberg, 1950 (map)
100	Centrosaurus	LS 1934	skull I	2135′	292′	N				Sternberg, 1950 (map)
101	Lambeosaurus	LS 1920	skull I	2314′	108′	Y	clean ss. I	at 28' in 29' channel ss.	channel top	Sternberg, 1950 (map)
102	hooded hadrosaur	CHS 1914	skeleton, no head E	2258′	164′	Y 100°	fine ss. with lam. veg. II	at 8' in 12' ss. with some clayballs much lam. veg.; 20" clay; above: more channel ss.	channel fill	Sternberg, 1950 (map)
103	plated dinosaur	LS 1921	parts	2180′	247′	Y	xs bd ss. with clayballs, veg. V	base of 15' channel ss.; below: clay	base of channel	
104	Centrosaurus	CHS 1913	skull less jaws I	2166′	256′	Y	silty clay VII	at 23' in 36' clay, silty clay with minor fine ss., rootlets	floodplain	Lull, 1933
105	Scolosaurus cutleri	WEC 1914	complete exc. most of skull lost A	2171′	246′	N				Lapparent & Lavocat, 1955
106	Styracosaurus albertensis	CHS 1913 LS 1935	skull and jaws; postcranium scattered C	2328′	86′	Y	ss. with xs lam. veg. II	10' in 27' channel ss.	channel	Brown & Schlaikjer, 1937
107	Centrosaurus	CMS 1921	skull lacking frill; 1 tibia, 2 squamosals; scattered D	2182′	232′	N				Sternberg, field notes, 1921

Table II. cont.

Quarry No.	Specimen	Collector Date	Condition / Preservation Class (see Table VI)	Elevation	Strat. Posit. below Bearpaw	Quarry found ? axis	Lithology (see Table II)	Position in Section	Interpreted Environment	Source
108	Corythosaurus casuarius	CMS 1921	skull I	2217'	198'	Y	xs bd ss. with veg. II	at 2½' in 25' channel ss. with much xs veg.	channel	Sternberg, 1950 (map)
110	? Gryposaurus	CMS 1921	pt. of skull, scattered neck, dorsals partly scattered, sacrum, tail base, legs, arms; end of tail scattered B	2292'	95'	Y 115°	clean ss. I	at 1' in 22' clean ss.	base of channel	Sternberg, field notes, 1921
111	Gryposaurus	CMS 1921	scattered skull parts; 1 rad., 1 corac., 1 fib., 1 metatarsal, several phalanges +ribs D	2195'	192'	Y	white ss. I	1-2' in 21' channel ss.	low in channel	Sternberg, field notes, 1921
112	Euoplocephalus	CHS 1914	much of scattered skeleton C	(2325'±)	(77)	N			channel	C.H. Sternberg, field notes, 1914 photos 29110, 29127, NMC
A	Corythosaurus cf. intermedius		nearly complete; tail lost by erosion A	2265'	159'	Y	ss. I	at 8' in 20' channel ss.	channel	Sternberg, 1970 park display no. 4
B	coelurosaur - uncollected		nearly complete; skull missing E	2200'	160'	135°	ss. I	at base of 7' ss. with minor silt, clay below; clay above	channel base	NE of Q 14:2,32,21,12, W.4 found in 1969
C	hadrosaur - uncollected		limbs somewhat scattered, no head (taken?), no tail present G	2200'	162'	Y 120°	silty ss. with veg. IV	below: clay; Q at base of 3½' ss; above: clear ss.	channel base	between Q 30 & 36 2,21,21,12,W.4 found in 1969
D	hadrosaur - uncollected		articulation quite good, no head A	2175'	187'	" 095°	ss. with some silt IV	below: channel ss; above 6' clay, ss; above: clay	upper	between Q 23 & 25: 14,21,21,12,W.4 found in 1969
E	hadrosaur		no head; left ilium drifted; scapula drifted E	2140'	260'	Y 110°	fine ss. I	xs bd ss. below; silty layers above	channel	park display no. 2

been mildly affected by Tertiary movement of the Sweetgrass Arch to the southeast (Wells, 1957). As the dip is slight and marker horizons in the Oldman Formation are lacking, the correct structural configuration is not detectable at the surface, but must be inferred by extrapolation from the subsurface. The first reliable marker horizon encountered at depth is the contact of the Pakowki Shale on the Milk River Sandstone, about a thousand feet below the surface. With well data obtained from the Schedule of Wells of the Oil and Gas Conservation Board of the Province of Alberta, a structure-contour map of the contact of the Pakowki and Milk River Formations was constructed (Fig. 11). It was then applied without modification to the Oldman Formation on the surface, and the elevations of the quarries were adjusted relative to one another, with the Bearpaw contact serving as datum (Table II). The dip is about 80 ft. per mile to the north. In the northwest corner of the Park there is a structural complication, possibly related to the trap responsible for the adjacent Cessford gas field.

The spread of the quarries is little affected by the structural correction, increasing only 4 ft. to 206 ft.; the fossils thus range from 86 ft. to 292 ft. below the Bearpaw Formation (Table II). It is important to decide if the paucity of fossils in the top hundred feet of the Oldman Formation is apparent or real. Therefore the outcrop pattern of the Bearpaw Formation was calculated and plotted for the Park, by means of the structure-contour map and a topographic map (quarry 109 served as the datum). Fig. 12 shows that the Bearpaw Formation crops out only near the eastern limit of the Park, where the relief is relatively great (about 400 ft.) and slopes steep. It is present in the

Fig. 11. STRUCTURE OF THE OLDMAN FORMATION AT DINOSAUR PROVINCIAL PARK

Legend

Configuration of the Pakowki/Milk River contact, contours in ft. above sea level, 25 ft. intervals

+1320 Well points, depth of contact indicated

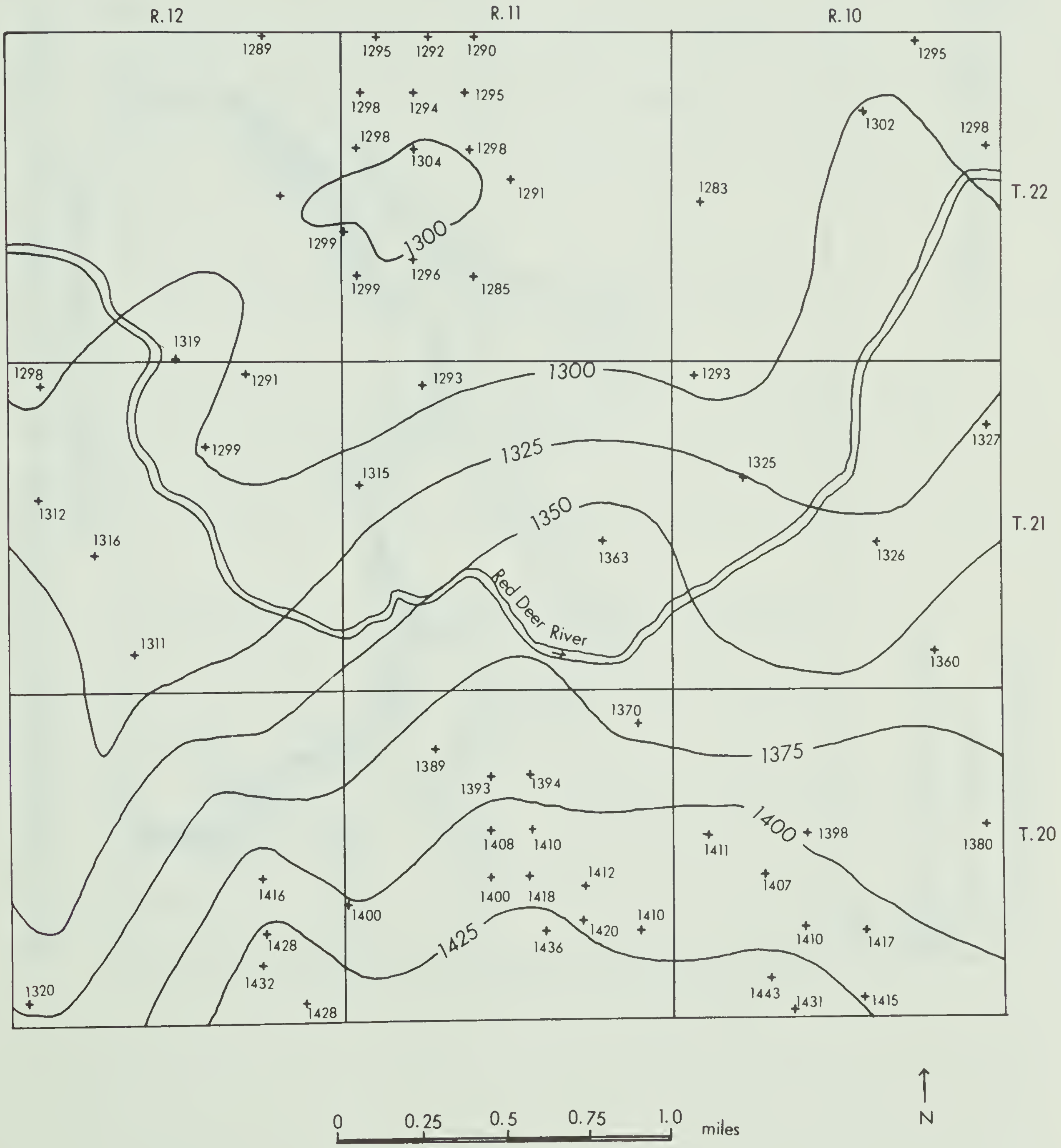
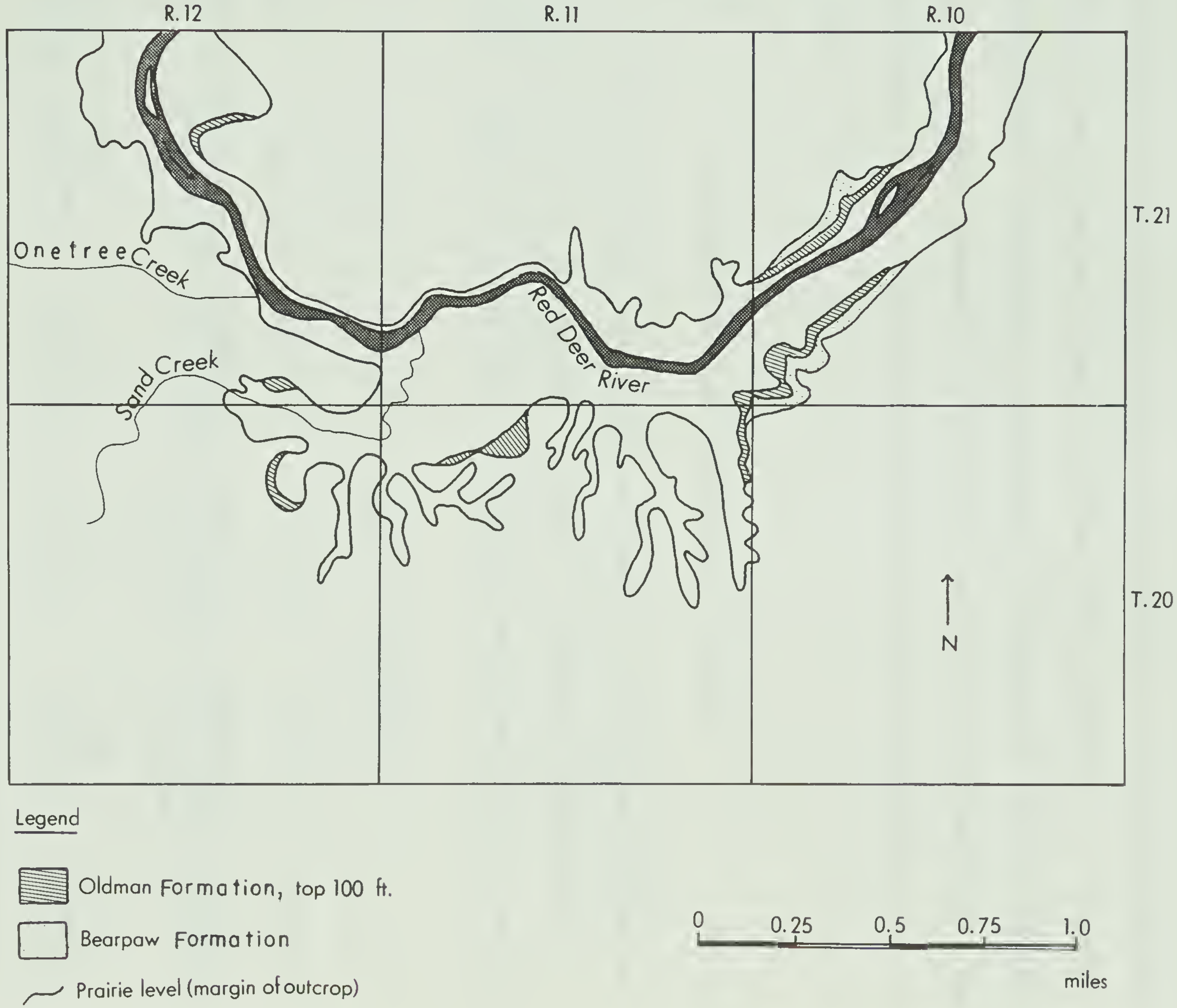


Fig. 12. DISTRIBUTION OF OUTCROP OF THE OLDMAN (top 100 ft.) AND BEARPAW FORMATIONS



vicinity of quarries 106 and 112 south of the river, and quarries 110 and 111 north of the river. In fact, the top hundred feet of the Oldman Formation itself has extremely limited exposure except in steep areas below the rim of the prairie, where exposures, mantled by glacial drift, are poor; the only significant horizontal exposure is a quarter square mile area. Therefore, the paucity of fossils in the top hundred feet of the Oldman Formation in this area may only be a function of the relative deficiency of accessible outcrop in that stratigraphic position.

Sedimentological Occurrence of Fossils

A basic goal of this study was simply to determine whether or not bone is randomly distributed through the various lithologies of the Park. Table III summarizes lithological data presented in Table II.

TABLE III SUMMARY OF QUARRY LITHOLOGIES

Class I	Class II	Class III	Class IV	Class V	Class VI
sandstone	sandstone, plant matter	sandstone, clay pebbles	sandstone, claystone, siltstone	sandstone, plant matter, claystone	silty claystone
48 quarries	13 quarries	7 quarries	6 quarries	9 quarries	1 quarry

It is apparent from Table III that quarried fossils are not randomly distributed, but have a strong tendency to occur in sandstone, especially clean sandstone (class I),and are markedly deficient within claystones and siltstones. Of 84 quarries examined, only quarry 104 was found to be in a non-sandy sediment (class VI). Environmentally

this may be expressed by noting that fossils are usually found in channel deposits, sometimes in channel fill deposits, and rarely in floodbasin deposits (Tables II and VI).

The scarcity of bone in claystone is real. It is true that bone is not as well preserved in claystones as in sandstones, because the expansion of the montmorillonite-rich claystones on weathering is very destructive; therefore weathered specimens in such sediments were unattractive to collectors. In the course of field work for this study, bones were found in claystone in only 3 of the 84 sections measured, in contrast to the locally abundant scattered bone in sandstone. Field parties from the University of Alberta have observed several significant specimens in claystone, including a small turtle skull and remains of a juvenile hadrosaur (R.C.Fox, pers. comm., 1970); however, they corroborate the general scarcity of bone in this lithotope.

Elsewhere, other sets of conditions have led to other characteristic modes of occurrence. For example, Hotton (1967) reported that in the Beaufort Series of South Africa, bone found in sandstone is fragmentary and water-worn, whereas articulated skeletal materials are found in shales and siltstones. Olson (1962, p. 106), describing the occurrence of bone in the Permian San Angelo Formation of Texas, noted that while bone was rarely found in channel sandstones, that which is found there is generally in excellent condition. In Oligocene deposits of western South Dakota, good fossils are generally found in siltstones and claystones that are floodplain deposits (for example, Clark _et al._, 1967).

The scarcity of bone in claystone in the Oldman Formation may be the result of scarcity of animals in the regions where clay was

being deposited, or may be the result of failure of remains deposited there to be preserved to the present time. If the latter were the case, destruction may have been the consequence of low rates of sedimentation leading to disintegration before burial, or may have resulted from diagenetic elimination after burial.

The overwhelming majority of fossils, 72 of 84, were found in various channel environments, as opposed to quiet water and overbank environments (Table VI). In some cases (quarries 47 and 86), hadrosaur skeletons were found lying on their backs, apparently having floated upside down (C.M. Sternberg, unpubl. field notes, 1917, 1936). Occasionally a skeleton is found with the head dragged underneath the shoulder (Sternberg, 1970).

The frequent occurrence of highly articulated dinosaur skeletons in channel lithotopes, coupled with the striking paucity of such remains in topstratum deposits, strongly suggests that the dinosaurs preserved in channel deposits died in the water; Sternberg (pers. comm., 1969) independently expressed the same view. It is not difficult to visualize the introduction of limited numbers of carcasses into a channel under special circumstances such as flooding, but if death on land were the rule, the gross favoring of the channel environment over the floodplain as an environment of preservation would hardly be expected. It seems unlikely that a rotted carcass could be transferred from a bank area into a channel and be preserved in a highly articulated state, as so many skeletons were. Factual modern observations on these matters are urgently required.

The directions of long bones observed in the field were measured, with the hope that this information might document current transport,

as Voorhies (1969) was able to do. A plot of 49 axes (Fig. 13) however, apparently fails to show any marked directional control. This may reflect the variability of the current system over a large area, coupled with the fact that bones may be transported either parallel or transverse to the current (Voorhies, 1969).

Axes of quarries were also measured to the extent that they could potentially reveal the orientation of the fossils removed (Fig. 14). Corroboration by use of original photos (National Museum of Canada and American Museum of Natural History), where available, supplemented inferences made from quarries themselves. A plot of 33 quarry axes indicates a moderate tendency for a north-south alignment, about perpendicular to the prevailing current direction, with an almost equal tendency for alignment sub-parallel to the current. This suggests transport of carcasses by current action.

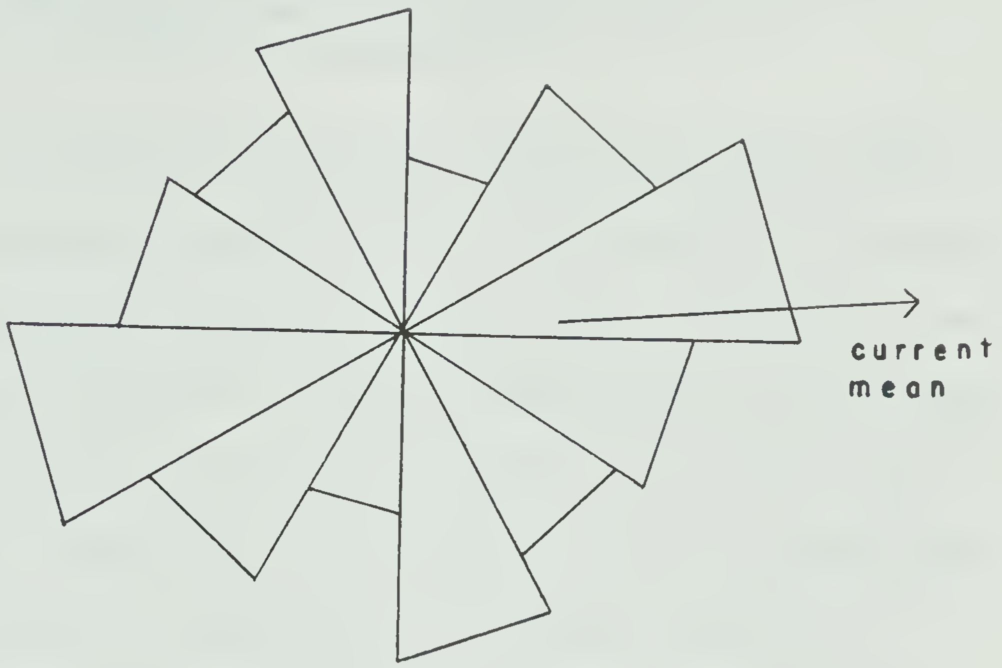
Decay and Transport of Fossils

A striking observation concerning fossils from the Oldman Formation is that they are found in a wide spectrum of degrees of completeness, from whole skeletons to isolated bones or bone fragments. The interpretation of classes on this spectrum with respect to lithological environments constitutes a major goal of taphonomic enquiry. Efremov (1953: 100-101) made an important statement with regard to this problem (translated from French by the present writer):

> "For little decomposed animal remains and the majority of plant remains, transport in the form of suspensions, for example as floating cadavers, tree trunks, etc., is an extremely important mode of movement. Transport by floating can be accomplished no matter what the speed of the current, and for a long distance. The limit of the distance traveled is determined by the speed of decomposition of the cadaver and plant remains which, at an advanced stage of their decomposition

Fig. 13. Summary of Axes of Isolated Bones

n= 49



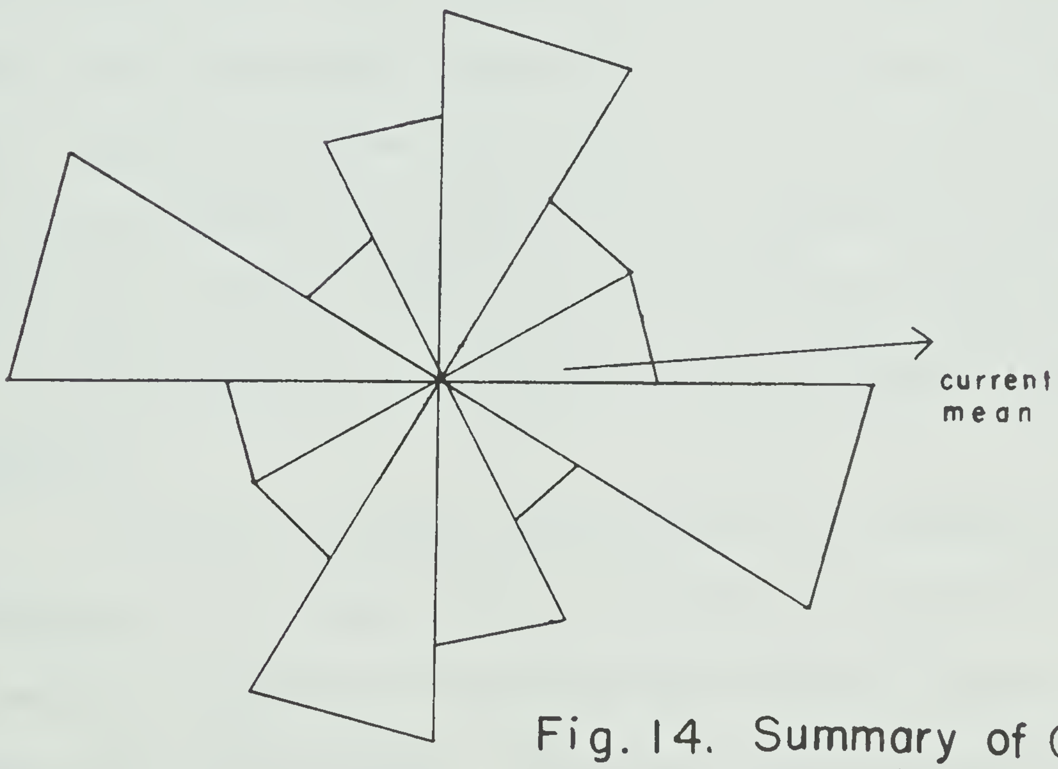


Fig. 14. Summary of Quarry Axes

n= 31

(including an axis from Parks, 1920)

> sink and fall to the bottom. After this submersion, if the force of the current is still sufficient, the remains move by dragging along the bottom and are progressively dissociated and distributed according to the density of different elements. If, on the contrary, the speed of the stream is very weak already, as for example in the region of deltas, the cadavers and other remains stay on the bottom and are buried in the sediments."

An intuitive generalization may be formulated, based in part on Efremov's observations, that the degree of articulation of a fossil is inversely proportional to the time elapsed between the death of an animal and its definitive burial. Elegant observations have been made on the process of decomposition of fishes (Müller, 1951, 1963; Barthel, 1966), but no similar observations have been made on the decomposition of tetrapods in subaqueous circumstances. Voorhies (1969) has experimented with disarticulated skeletons of coyotes and sheep in a flume, and noted, among other things, that ribs and vertebrae tend to move readily, even under the influence of slow currents, skulls tend to resist movement, and limb bones are intermediate in hydraulic properties. Similar observations are needed for larger animals in order to assess the effects of current winnowing on skeletal elements of dinosaurs.

In lieu of recorded observations on the decomposition of tetrapods in the course of fluvial transport, an attempt can be made to formulate a hypothetical decompositional series, consistent with the condition of known fossils. There are obviously many factors complicating this task. For instance, the roles of predation and scavenging, difficult to assess, are potentially of great importance, for these activities can accomplish at the time of death of an animal mechanical disintegration that might otherwise take months to bring about. However, no osteological

evidence has been observed on any skeletons collected from the Oldman Formation to indicate that such activities have taken place (Ostrom, 1964). But with diverse theropods, large and small on land, and crocodiles in the water, it is inconceivable that such events were other than commonplace. In the field, isolated limb bones or fragments of limb bones were occasionally found with long, deep grooves (Fig. 15), evidently the work of a strong carnivore such as Albertosaurus (=Gorgosaurus: D.A. Russell, pers. comm., 1967). It is possible, therefore, that the scattering of skeletons prior to burial may in some cases be attributable to the action of predators or scavengers. At quarry 28, a skull of Procheneosaurus cranibrevis was found with the neck still attached (Fig. 16); the skeleton was present but scattered (Sternberg, unpubl. field notes, 1928). Predation may explain the otherwise incongruous presence of the neck still attached to the skull, for these parts,usually among the first to be attacked by decay, would seem relatively undesirable as food. On the other hand, at quarry 72, where a scattered skeleton of Corythosaurus excavatus was found, the skull itself was scattered but part of the vertebral column and limbs were still articulated (Fig. 17). A predator would not be expected to carefully dismember a skull and leave the ribs intact. Rather, it appears that subaqueous exposure permitted decomposition to proceed to a relatively advanced stage under quiet conditions.

In spite of the limiting factors, an attempt was made to construct a classification assigning the fossils to categories of essentially similar condition. The parameters of classification are degree of completeness of the specimen, and degree of scattering. Every effort was made to determine the effect of erosion on incomplete

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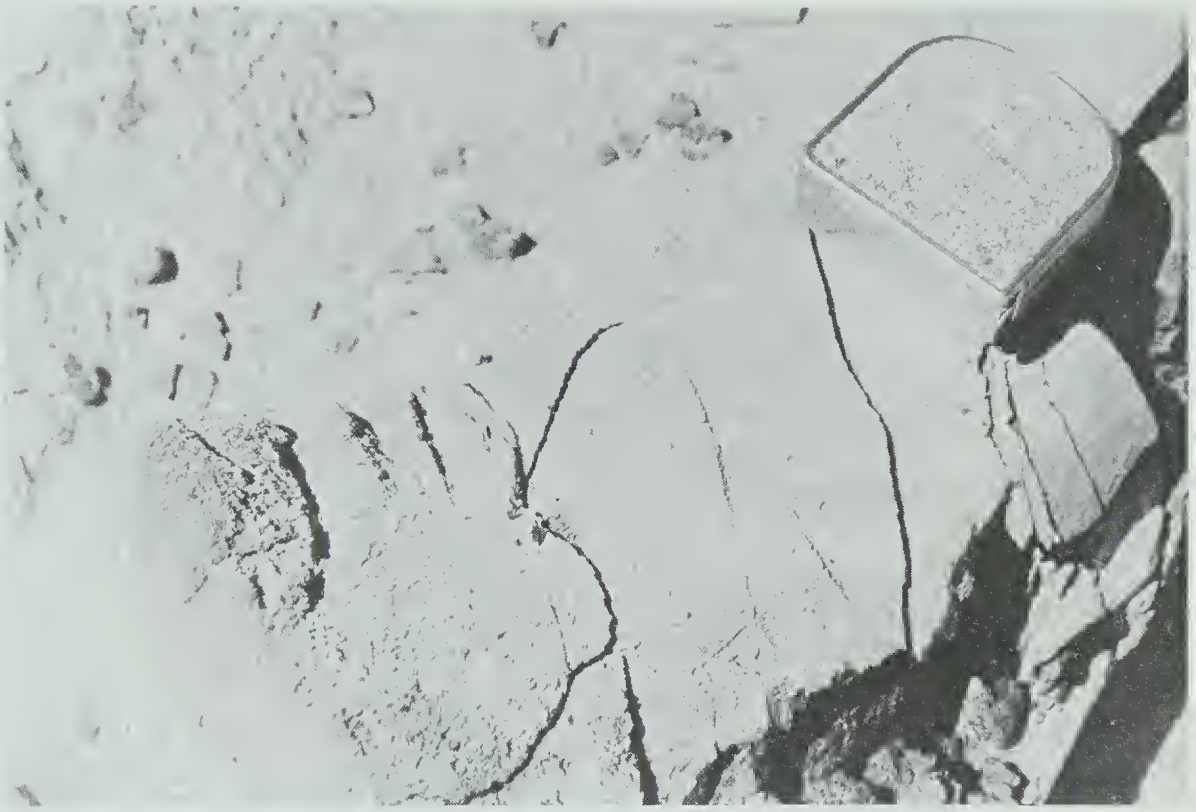

Fig. 15. Large Bone with Tooth Marks, near Quarry 9

(photo courtesy of National Museum of Canada)

Fig. 16. Skull of Procheneosaurus cranibrevis with Neck Attached, Quarry 28

(photo courtesy of National Museum of Canada)

Fig. 17. Scattered Skeleton of Corythosaurus excavatus at Quarry 72; part of vertebral column (poorly shown) and limbs still articulated

specimens, by means of field evidence and collectors' field notes and photos, so that the classification does not merely document the effect of erosion. In some cases, inferences were made where seemingly warranted; such inferences are noted. A category was formulated for the reception of specimens for which condition, due to obvious erosion, did not allow useful classification, or for which no adequate information could be obtained. The assignment of each fossil and the source of information are listed in Table II.

It must be stressed that, whereas the faunal list for the Oldman Formation may, with modification, be regarded as indicative of the relative abundance of various dinosaurs (Russell, 1967a), the scheme presented here is in no way indicative of the relative proportions of various types of fossils, articulated or disarticulated. For every articulated specimen collected from the Park, quite literally hundreds of bones or bone fragments are passed by.

The classification is as follows:

TABLE IV DECOMPOSITIONAL CLASSES OF DINOSUARS

Class A:	specimen complete or nearly so
Class B:	specimen complete or nearly so, some drifting of major elements
Class C:	skull and scattered skeleton
Class D:	skull and scattered bones
Class E:	skeletons without heads
Class F:	skull with incomplete articulated skeleton
Class G:	incomplete articulated skeleton
Class H:	skull with jaws
Class I:	skull without jaws
Class J:	isolated bones
Class K:	incomplete articulated specimens-extent of original specimen unknown

Tables V and VI present a detailed description of each class with respect to lithology and environment, respectively.

Class A, consisting of complete articulated specimens buried relatively rapidly after death (Fig. 18), is the largest group as it contains the best display material. Occasionally, complete specimens found in the Oldman Formation exhibit impressions of portions of the integument (for instance, Lull, 1933; Lull and Wright, 1942). However, spectacular mummies such as have come from the Lance Formation of Wyoming are unknown. There is a strong tendency for such specimens to occur in clean sandstones (12 of 17 specimens- Table V), which correspond to channel and channel base environments (Table VI). Complete specimens therefore seem to represent carcasses of animals that died in water, floated for a distance and came to rest in the channel. Less frequently, carcasses came to rest in conditions of slowing current or in backwaters or channel fill (6 of 17- Table VI).

Class B represents those specimens that are more or less complete, but in which minor movement of certain elements (drifting) has occurred (Fig. 19), which indicates that burial followed a period of subaqueous exposure under relatively quiet conditions, during which decomposition had begun to act on extremities, but with energy conditions too low for major scattering to take place. At quarry 30, for example, the type specimen of Lambeosaurus clavinitialis was a complete skeleton lying on its side. The skull had separated from the neck, the lower jaws, left jugal and maxilla were scattered, and the left scapula had separated from the trunk, but the forelimb was still articulated to it (Sternberg, unpubl. field notes, 1928). Elements that are particularly susceptible to drift are: the skull, which may be partially disarticulated as well as separated from the neck (specimens from quarries 30, 68, 86, 88, 110); the humerus or scapula

(photo courtesy of American Museum of Natural History)

Fig. 18. A Complete Skeleton of Corythosaurus casuarius (type), Quarry 1

(photo courtesy of National Museum of Canada)

Fig. 19. A Drifted Skeleton of Corythosaurus intermedius from Quarry 68; tail lost through erosion, head still covered

TABLE V DECOMPOSITIONAL CLASSES AND LITHOLOGY

Lithologies (Table III) / Decompositional Classes (Table IV)	Class I sandstone	Class II sandstone, plant matter	Class III sandstone, clay pebbles	Class IV sandstone, claystone, siltstone	Class V sandstone, plant matter, claystone	Class VI silty claystone
Class A: complete	Q1,9,27,31 52,54,83,84 86,94,A	Q43		Q21,37,D	Q36,38	
Class B: complete, drifted	Q46,48,77, 86,110			Q88	Q30,47,68, 69	
Class C: complete, scattered		Q3,106	Q28,72,82			
Class D: skull, a few bones	Q59,62,65, 111					
Class E: skeleton, no head	Q34,B,E	Q44,102			Q35	
Class F: skull, part of skeleton	Q2,87,96	Q98		Q70		
Class G: part of skel., no head	Q93	Q50			QC	
Class H: skull, jaws	Q17,32,71, 74	Q19	Q85			
Class I: skull, no jaws	Q4,5,22,26, 33,41,42	Q81,108	Q13			Q104
Class J: isolated bones	Q7,60					
Class K: condition unknown	Q16,39,40, 55,73,92	Q12,20,76	Q15,18		Q24	

TABLE VI DECOMPOSITIONAL CLASSES AND ENVIRONMENT

Environment (Table II) / Decompositional Classes (Table IV)	Channel	Channel Base	Channel Top	Slow Channel	Shallow Channel	Channel Fill	Flood-plain
Class A: complete	Q1,9,27,43, 52,54,83,84, A	Q31,94	QD	Q36		Q21,37, 38,86	
Class B: complete, drifted	Q48,68,77	Q47,110	Q30	Q46,69		Q86,88	
Class C; complete, scattered	Q28,82,106	Q72		Q3			
Class D: skull, a few bones	Q59,62,65 111						
Class E: skeleton, no head	QE	QB	Q34	Q44		Q35,102	
Class F: skull, part of skeleton	Q2,96	Q98		Q87		Q70	
Class G: part of skel., no head	Q93	Q50,C					
Class H: skull, jaws	Q17,19,71, 74		Q85	Q32			
Class I: skull, no jaws	Q4,5,26 66,81,108	Q41,42	Q101		Q13,97	Q22,33	Q104
Class J: isolated bones	Q60	Q7					
Class K: condition unknown	Q16,18,40, 55,73,76,92	Q12,39	Q15,24	Q20			

[illegible]

(quarries 30, 47, 68); the ilium (quarries 46, 88); and the tail, beginning with the distal portion (quarries 46, 68, 86, 110). Such specimens show less of a tendency to occur in clean sandstones than do complete specimens (only 5 of 10),more of a tendency to occur in sandstones with vegetable material and clay, which correspond to low energy channels or backwaters (channel fill).

Quarries 48 and 77 are inferred to belong to Class B. From the former came part of a skeleton of Albertosaurus that was partially articulated but somewhat scattered, although the details are unknown. At the latter, a ceratopsian skeleton described as "scattered" (G.F. Sternberg, unpubl. field notes, 1920) was left behind, but the description indicates that there was considerable articulation, so drifting rather than complete scattering is inferred.

C is the class that contains skulls with scattered skeletons in minimal articulation. One might expect these to represent culmination of decomposition in quiet water, but the field evidence does not seem to support this conclusion, as 4 of 5 specimens came from channel or channel base environments (Table VI). Lithologies are not clean sandstones, however, and at least the vegetable-rich sediments may indicate somewhat reduced current velocities. Predation or scavenging may have affected this class, as discussed earlier. Stegoceras validus from quarry 3 is inferred to belong to this class because it is relatively incomplete, but lacks fragmentary bone resulting from erosional destruction.

Class D consists of skulls associated with a few disarticulated postcranial bones, especially limb bones and scapulae. The four examples were found in channel sandstones. The presence of ribs along

with skulls (quarries 62, 111) is puzzling, as Voorhies (1969) noted that the former are most easily moved, readily transported even by slow currents, while the latter are most resistant to any current action. Such deposits as these serve to emphasize the total inadequacy of our knowledge of how fossils relate as clastic particles to the sediments in which they are enclosed. Again predation may possibly account for such associations.

E is the class that consists of skeletons without heads. Such preservation is relatively common in the fossil record. For instance, Weigelt (1927) and Efremov (1953) both mention such fossils, and headless sauropods are common from the Upper Jurassic Morrison Formation. Loss of the skull apparently represents an early stage of decomposition. If a carcass floating in a channel lost its head, no trace of the missing skull would be found with the skeleton; thus isolated skulls form a counterpart to this group. As decomposition continues, the forelimbs may be lost too (quarry 35, Fig. 20). Headless skeletons are found both in clean sandstones and in sandstones with vegetable matter and clay. In 2 of 6 cases the place of burial was a main channel, but the others came to rest in low energy channels or channel backwaters (channel fill deposits).

Class F contains skulls and incomplete articulated skeletons. To some extent this is a conservative category, containing some specimens that may have been complete but were subjected to an indeterminate amount of erosion (quarries 70, 96). This stage represents animals that have continued to decompose while being transported (see p. 66), but which have lost legs rather than skull (at quarry 96 the skull was scattered too). Such specimens were found in clean sandstone or sandstone

(photo courtesy of National Museum of Canada)

Fig. 20. Headless Hadrosaur Skeleton from Quarry 35; forearms missing too

with clay pebbles; three of five were found in channel deposits but the other two were buried where the energy conditions were lower.

Class G represents a further stage of decomposition of carcasses in the course of fluvial transport, and consists of articulated parts of skeletons. Specimen C (Table II), a somewhat drifted and deeply weathered skeleton found in 1969 was assigned to this class; however, a skull may have been collected from it at an earlier date-- if so, it should belong to Class F instead. All three specimens assigned to this class were found in channel sediments.

Classes H and I include isolated skulls with and without jaws respectively. Class I would seem to constitute a further stage of decay than Class H, but the geological evidence does not provide strong support for this conclusion . Five of 6 skulls with jaws (Class H) are found in sandstones or sandstones with clay pebbles, while 11 of the 14 skulls of Class I occur in these sediments. In Class H, 4 of the 6 skulls were found in channel deposits, 2 of 6 in low energy channel deposits; in Class I, 8 of 14 were found in channel deposits, 6 of 14 in slower water deposits. The slightly greater proportion of Class H skulls in channel deposits may reflect a tendency for more rapid burial in the channel than in environments of lower energy, with consequent decreased opportunity for decay to take place; the evidence is far from conclusive. It does seem safe to generalize that skulls of both types have a strong tendency to be deposited in channel sands.

Class J, consisting of isolated bones, contains but two bones, notwithstanding the fact that this group constitutes by far the most important class, quantitatively, in the Park. Both bones were found in the clean sandstones of channel deposits; this is typical for the

[illegible]

abundant isolated, current-transported bones of the Park.

Class K is a heterogeneous group, having no significance in itself, but receiving all specimens that could not be assigned to other classes. These include specimens obviously or possibly incomplete due to erosion, or specimens for which no satisfactory description could be located.

Fig. 21 expresses the inferred relationships of the various groups described above. Beginning from complete skeletons (A), headless skeletons (E) and drifted skeletons (B) are considered as roughly comparable early stages of decomposition, under conditions of channel transport and quiet water, respectively. Alternatively, under conditions of channel transport the skull may remain intact and limbs may instead be lost, resulting in partial skeletons with skulls (F), with isolated bones (J) a by-product. If a skull and partial skeleton decays, possibly under quiet conditions, and loose bones (J) are winnowed away by renewed current activity, a skull and isolated bones (D) may result. Further decay during transport of either the headless skeleton (E) or the skull and partial skeleton (F) may result in a partial articulated skeleton lacking a head (G), which will be ultimately reduced to isolated bones (J). Under quiet conditions, the end point of decay is represented by a skull and scattered skeleton (C). If scattered remains are subjected to increased current activity, winnowing may result in a skull with isolated bones (D) or, ultimately, isolated bones (J).

It must be emphasized that this scheme is hypothetical, and neglects action by predators and scavengers, which are fully capable of "artificially" producing any of the above stages immediately upon the death of the animal. The scheme does seem applicable, however, to the group of fossils to which it is applied.

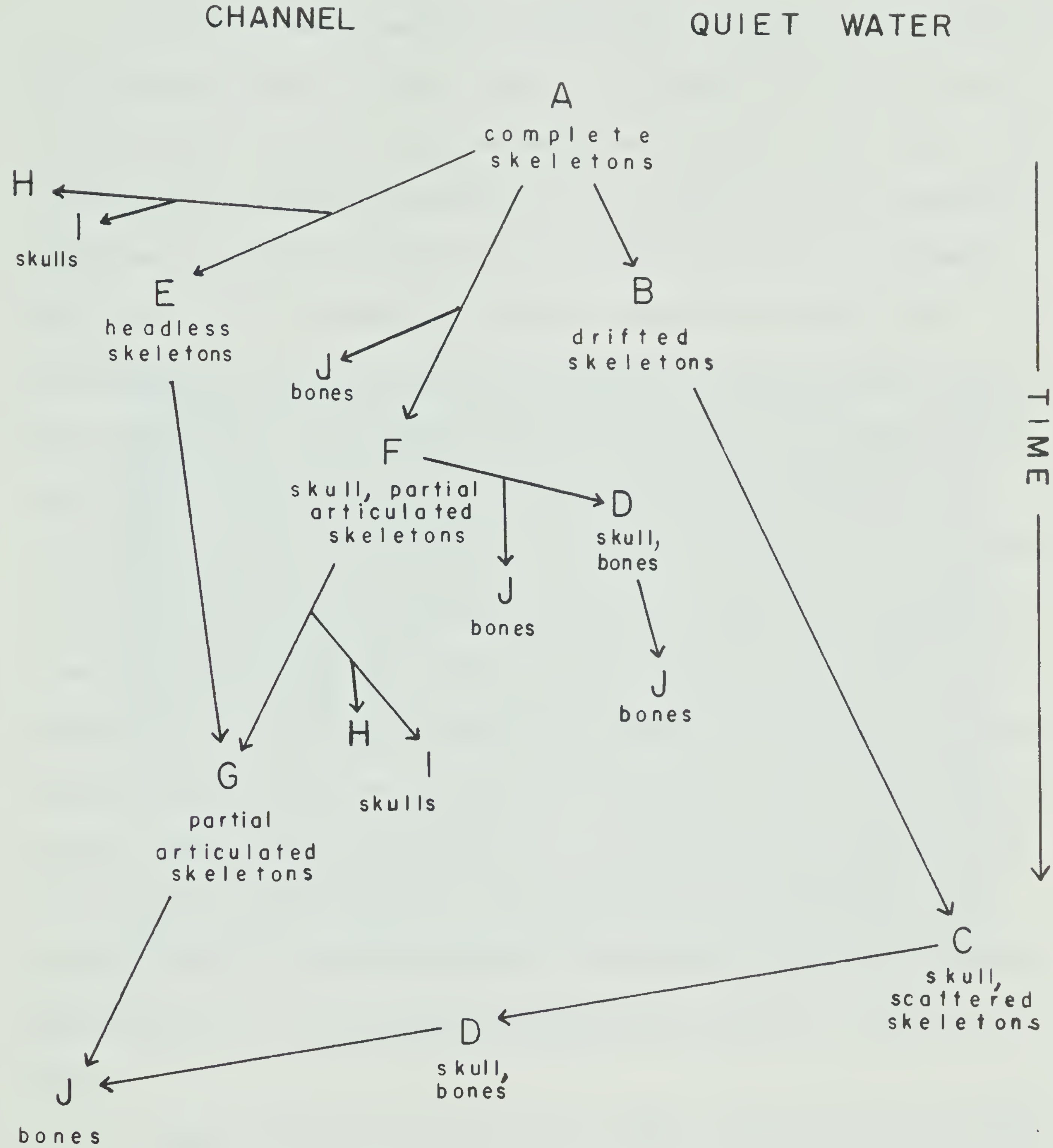

FIG. 21. INTERRELATIONSHIPS OF DECOMPOSITIONAL CLASSES

Occurrence of Non-quarry Bone

Two distinctive modes of occurrence of disarticulated bone in the Park are worthy of note. There is a tendency for bone to occur at the contact between claystone below and sandstone above (Fig. 22). In the numerous sections measured in this study, 22 of 80 claystone-sandstone interfaces yielded bone (including five quarry specimens) while only 2 of 69 sandstone-claystone interfaces yielded bone. Lithological interfaces have been recognized as significant sites for the preservation of bone (for instance, Weigelt, 1927; Efremov, 1953, pp. 115-116). Efremov described both sandstone-claystone and claystone-sandstone interfaces. He stated that the former, seen today on tropical floodplains subject to periodic inundation, are the more common in the geological record, and result from the sudden drop in velocity of a current after the flood peak passes, so that water-borne carcasses are dropped at the same time deposition of coarse sediment ceases. Such conditions apparently did not generally obtain at the time the Oldman Formation was being laid down. Discussion of the significance of claystone-sandstone interfaces is deferred to permit description of a second, highly characteristic mode of occurrence of bone.

There frequently occur in clay pebble sandstones concentrated assemblages of small bones, including such items as scales of _Lepisosteus_, a garpike, teeth of _Myledaphus_, a ray, and _Belonostomus_, a holostean, fragments of dermal spines of _Acipenser_, a sturgeon, teeth and dermal scutes of _Leidyosuchus_, a crocodile, vertebrae of _Champsosaurus_, a gavial-like eosuchian, fragments of carapace and plastron of turtles, small metapodial, podial, and ungual elements,

Fig. 22. Bone Weathering Out at a Claystone-Sandstone Interface near Quarry 9

and long bone fragments of dinosaurs, vertebrae of lizards and in some cases, mammalian teeth. Bones or fragments of bones in these assemblages are small, typically less than an inch long, often rather robust, and sometimes current abraded. The general similarity in size of the bones (most fall into the range of pebbles on the Wentworth scale- 4 to 64 mm.) suggests that these deposits represent hydraulic accumulations, and the generally chemically resistant nature of the bones, especially ganoid scales, enameloid teeth and small, light bones with a high proportion of dense, lamellar bone relative to cancellous bone suggests that these bones may represent some sort of chemical resistate. Thus bones in such concentrated assemblages may constitute end-products of thorough physical and/or chemical destruction of organisms, the remains of which have ultimately been concentrated as lag deposits in sandstone. It must be emphasized, however, that many teeth, scales, etc. show no signs whatsoever of abrasion.

The occurrence of bone at claystone-sandstone interfaces, and the association of concentrated assemblages of small bone in clay pebble sandstone may be related, at least in part. Clay pebbles in such intraformational conglomerates are often related to claystone-sandstone interfaces as basal conglomerates probably resulting from scour of a semi-consolidated overbank clay be renewed channel activity (Allen, 1962). About one quarter of the clay pebble horizons recorded in the field directly overlie claystones. The scattered bones encountered at the interfaces may represent thoroughly decomposed remains of animals that lay exposed on overbank areas (levee or floodplain), where unfavorable rates of sedimentation permitted complete disarticulation and partial destruction of skeletal materials; with

the return of major current activity to such a locality, the remains would have been swept away and scattered at the base of a channel, resting on clay. This applies equally well to the remains of animals contributing to the concentrated assemblages of small bones in clay pebble sandstones, inasmuch as basal scour gives rise to clay pebbles (Allen, 1962). For three quarters of the occurrences, collapse of a bank is a better explanation for the clay pebbles (Dunbar and Rogers, 1957). The small bones lying exposed on the bank would have been dumped into the channel by the collapse. For both basal scour and bank collapse, the net result is the same: decomposed remains associated with clay pebbles are introduced into a channel, and come to rest as lag deposits, in the former case, resting on a clay, in the latter, contained within a channel sand. Thus, there is no difference in kind between the occurrence of scattered bone at claystone-sandstone interfaces and the occurrence of concentrated assemblages of small bone with clay pebbles at these interfaces.

Efremov (1953, p. 116) noted that beds that are "in general composed of pebbles and conglomerates, and are distinguished by an abundant accumulation of damaged remains, this accumulation being the consequence of the intrusion of a powerful current of water into the region of calm sedimentation, causing a rapid and disorderly movement of a great mass of organic remains. In these beds, one finds almost no complete skeletons, the remains of small forms are either carried away, or are destroyed and are only found in pockets, that are ravines in the lower beds." Although such "pockets" are not seen in the Park, a similar process doubtlessly applied.

Bonebeds constitute a striking taphonomic feature of the Oldman

Formation. Some, such as those near quarries 72, 83, and 98, are quite local in extent, and measure no more than 50 yds. in greatest dimension, but others, such as one north of Onetree Creek, apparently extends for more than a mile (Fox, pers. comm., 1969). Sternberg (1970) believes some Oldman bonebeds to consist almost exclusively of the remains of a single genus of ceratopsian, *Styracosaurus* in one case and *Centrosaurus* in others. Oldman bonebeds probably represent mechanical accumulations of disarticulated bones under favorable conditions of deposition, such as channel backwaters. Systematic investigation of the type, size, orientation and condition of the bones, as well as sedimentary association (Voorhies, 1969) would be necessary to verify this. Such an undertaking was beyond the scope of this project.

INFERENCES

The evidence outlined in the previous section clearly indicates that the fauna of the Oldman Formation is an allochthonous fauna; such is normally the case for terrestrial faunas (Efremov, 1953; Brouwer, 1967). It is not possible to estimate distances traveled by floating carcasses; here, especially, modern observations would be extremely valuable. However, it does seem reasonable to suppose that the fossils recovered represent a fauna that lived fairly close by; presumably, a biological prerequisite for the formation of such fossil beds is the proximity of a large or at least dense population of animals (Efremov, 1953, pp. 95-96). Also, the large proportion of herbivorous dinosaurs collected relative to carnivorous forms (similar to the proportions of these in the Edmonton Formation- Russell, 1967a) seems indicative of the Eltonian balance of a living fauna (Shotwell, 1955). So, although the fauna of the Oldman Formation is transported, it probably provides an adequate profile of the dinosaurian fauna extant in the region at the time (this statement most emphatically does not apply to such animals as lizards, salamanders and mammals that, by virtue of their small size, are seriously under-preserved, and have been seriously under-collected and under-studied until very recently- Fox, 1968a, 1968b).

Shotwell (1955) presented a technique for identifying "proximal" and "distal" members of fossil assemblages in a quantitative fashion. Some of his assumptions have been criticized recently (Voorhies, 1969), but his fundamental premise seems axiomatic, that members of a proximal community will consistently be represented by a greater number of specimens with a higher degree of completeness than will members of

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distal communities. This is a corollary of the proposition that the amount of decomposition is proportional to be amount of time elapsed between death and burial.

On the basis of these assumptions, several inferences can be drawn concerning certain dinosaurs of the Oldman Formation. Ceratopsian dinosaurs, notably Centrosaurus and Chasmosaurus, are regularly found in a high degree of articulation in the Oldman Formation (Russell, 1967a). Their condition as fossils is entirely comparable to that of hadrosaurs, and they may be confidently assigned to the same proximal community as hadrosaurs. This is contrary to one school of thought that in the past has designated ceratopsians as "upland" forms (for example, Colbert, 1961, p. 202). Styracosaurus and Monoclonius (provided that this is a valid genus, as Russell (1967a) believes) were far less common, and may be properly referrable to a more distal community.

Ankylosaurs are significantly less common than hadrosaurs and ceratopsians, as they constitute only about 11% of the known fauna (Russell, 1967a). They too may properly belong to a more distal habitat. Additional evidence for this is that scutes of ankylosaurs are relatively common in the Park, but their heavy tail clubs, which would have been transportable only with great difficulty, are rare. Certain dinosaurs are exceedingly rare, and almost certainly are represented by fortuitous appearances of animals that habitually inhabited other environments in other areas. These include the hadrosaurs, Brachylophosaurus and Parasaurolophus, the small theropods, Dromaeosaurus, Stenonychosaurus, Macrophalangia and Chirostenotes, and the strange pachycephalosaurid, Stegoceras.

The proximal environment probably consisted of the swampy lowland alluvial plains adjacent to rivers so frequently referred to in the literature of North American Late Cretaceous vertebrates (for instance, Estes, 1964; Ostrom, 1964; Russell, 1967b). The nature of the distal environments is less clear. It is possible that rare dinosaurs in the Park were simply brought in from farther upstream (west) in a passive manner. If so, similar riparian habitats must have pertained there as well. Another possibility, perhaps more satisfactory, is that the distal habitats were drier and less aquatic. This need not correspond to the "upland", mysterious breeding ground and nursery of the dinosaurs (Sternberg, 1955), but simply to better drained interfluves situated lateral to the floodplains. The upland has been assumed to lie farther to the west, on the assumption that dry interfluves would increase relative to alluvial plains with increasing distance from the sea. However, this was not necessarily the case. Olson (1962, p. 127), discussing streams of Late Permian age in Russia, where a similar tectonic framework prevailed, postulated that the relatively short streams were parallel to each other and of low drainage order, in no way comparable to a highly integrated drainage system such as the Mississippi today. If the analogy between Permian Russia and Late Cretaceous North America is correct, the relative proportion of dry interfluve would not increase significantly towards the source area, and the dinosaurian nursery should not be sought to the west, unless in the tectonic highland itself. Belly River sediments in the Foothills are similar to Oldman sediments in the park, 150 miles to the northeast, especially in the lack of obvious channels (Lerbekmo, pers. comm., 1970), and seem to indicate similar environmental

conditions. Thus, a very broad, low coastal plain, perhaps 200 miles or more wide is indicated by the sediments. Belly River sediments are truncated in the Foothills by structural complications, so the record of conditions farther west is unavailable. The apparent similarity of conditions across the broad, low coastal plain demonstrates that the upland could not have existed between the Park and the Foothills. If dinosaurs genuinely did breed and raise their young in the upland, they would have had to migrate 200 miles to the Park as young adults. This is an unnecessarily cumbersome explanation to account for the paucity of juvenile dinosaurs. If juvenile dinosaurs preferred relatively dry conditions, they must have lived in interfluves lateral to the streams whose deposits are presently found in the Park, and not several hundred miles away. However, Richmond (1965) demonstrated that in populations of long-lived animals with developmental period very short relative to reproductive period, and with low mortality rates during the reproductive period, population size could remain stable at very low reproductive rates. Dinosaurs in all probability met these conditions. Therefore, the paucity of specimens of juvenile dinosaurs is probably due in large measure to genuine scarcity of these animals in life rather than to their maturation elsewhere.

It was suggested in the previous section that the dinosaurs of the Oldman Formation died in the water, that is, in channel areas. By extrapolation, it is logical to suggest that the dinosaurs lived in the water. This is not to suggest that they were solely aquatic, but neither were they solely terrestrial. It is probable that they spent significant portions of their time in water. Ostrom (1964) argued strongly for a dominantly terrestrial habitus for hadrosaurs. He

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argued that their limited swimming ability served mainly to permit them "to migrate across swamps and rivers in their search for food or to escape from terrestrial predators by retreating to the security of these waters". It seems highly probable, on the basis of taphonomic evidence presented here, that notwithstanding the undoubtedly important terrestrial component of their diet, hadrosaurs spent significant (but not necessarily dominant) portions of their time in water. Ceratopsians seem ill-suited for aquatic grazing (Hotton, 1963, p. 102), but on the basis of their geological occurrence identical to that of hadrosaurs, it seems very probable that they could swim. Ostrom's comment quoted above may be more properly applicable to ceratopsians than to hadrosaurs. The proportion of hadrosaurs recovered from the Oldman Formation relative to ceratopsians, about 42% of the total fauna versus 24% (Russell, 1967b),may reflect the relative preferences of each for the aquatic habitat, rather than true numerical superiority of hadrosaurs over ceratopsians. Finally, it seems probable that the water's edge did not constitute an impassable barrier to carnosaurs, which probably waded in after prey, but were likely rendered ineffective with increasing depth.

The above comments are admittedly speculative. Their validity ultimately rests on the correctness of the interpretation that dinosaurs of the Oldman Formation spent significant portions of their time in water. This conclusion stems from the fact that these dinosaurs are regularly found, with a high degree of completeness and articulation, in channel lithotopes, and are almost entirely absent from lithotopes indicative of floodplain environments. In other situations where floodplain faunas have been identified, sediments have given some

indication of floodplain conditions (for example, Shotwell, 1955; Clark et al., 1967; Voorhies, 1969). It is felt, for these reasons, that if the dinosaurs of the Oldman Formation had but superficial contact with water (such as drinking at the water's edge) and preferred a dominantly terrestrial habitus, that some indication of this would be found in the sediments.

There is an implicit assumption, as well, that channels and subaerial environments were relatively distinct. If, on the other hand, braiding was extremely extensive, the whole area might have been quite literally awash, and dinosaurs would have been constantly slogging from one small feeding area to the next. Under these conditions, the taphonomic conclusions of this report would have no validity. But such a system of evanescent channels and bars would seem unfavorable to the development of enormous quantities of lush vegetation required to support abundant, large-bodied herbivores, so this suggestion does not seem likely.

It must be emphasized that the conclusions reached in this study do not apply to the Oldman Formation as a whole, but only to the locality studied, Dinosaur Provincial Park, Alberta. Other localities in the Oldman Formation, such as those near Hilda and Irvine and on the Milk River, all in southern Alberta, have their own taphonomic characteristics, and may show ecological differences as well (R.C. Fox, pers. comm., 1969). These sites require separate study.

SUMMARY

In Upper Cretaceous (Campanian) dinosaur-bearing sediments of the Oldman Formation as exposed at Dinosaur Provincial Park in southern Alberta, it is possible to recognize various alluvial deposits, including channel, channel fill, levee and floodbasin deposits. The dominance of channel deposits suggests that braided streams were important, although cycles characteristic of meandering streams are also present. Paleocurrent observations demonstrate that the source of Oldman detritus lay almost due west of the Park. Molluscs, plant fossils, and remains of lower vertebrates, especially salamanders, indicate freshwater conditions pertained, and a search for Foraminifera, potential indicators of salinity, yielded but four specimens, three of which are referable to genera known to be very tolerant of reduced salinities today. Current interpretations of floral assemblages suggest that the climate was warm and equable. As annual growth rings in wood and vertebrae of _Champsosaurus_ clearly show that the climate was seasonal, seasonal control must have been exercised by rainfall, not temperature; the rains would not have been monsoonal. A study of the geological occurrence of 84 known vertebrate fossils reveals that bone is not distributed randomly through the sandstones, siltstones and claystones, but has a strong tendency to occur in channel sandstones, especially clean ones, and is notably scarce in claystones. From this it is concluded that dinosaurs preserved in channels died in channels; if death on land were the rule, evidence of fossils in overbank environments would be expected. Dinosaurs representing all stages of decomposition are found, and it is possible to infer from these, and from their lithological associations,

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stages of progressive decomposition of dinosaurs, in both channel and quiet water environments. Other characteristic modes of occurrence of bone include the presence of scattered bone at claystone-sandstone interfaces (with the sandstone above the claystone); concentrations of small bone in clay pebble intraformational conglomerates; and bonebeds. It is concluded that ceratopsians, by virtue of their occurrence entirely comparable to that of hadrosaurs, were inhabitants of the swampy lowlands along with hadrosaurs, and thus were not "upland" dwellers. Certain dinosaurs, such as ankylosaurs and small theropods, may have lived in more distal habitats. Speculation is offered that hadrosaurs, and to a lesser extent, ceratopsians and possibly even carnosaurs, because of their apparent deaths in the water, may have spent significant portions of their daily lives in water. Geological evidence indicates that upland environments lay more than 150 miles to the west, and therefore would not have provided suitable environments for raising young dinosaurs. Possibly dinosaurs bred in dry areas lateral to streams.

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APPENDIX A. DESCRIPTION OF MEASURED SECTIONS

Quarry 1: 17' veg-rich clay-silt, brn low in unit, yel in middle; 44" silt, no veg; 1 1/2' - 6 1/2' ss, minor veg, clay peb, Q at 4'; 30" clay with bone (at interface too).

Quarry 2: clay; 7'ss; 24' interbedded silt, f ss, large xs bds; 23' clay; 4' ss; 5" lenticle clay peb; 14" ss, lam veg; 3' lenticle clay peb; 3 1/2' - 6' ss, Q near base; 5' - 7' red lam veg, ss and clay, Fe st; 6' xs bd ss with lam veg, clay peb, bone conc at base.

Quarry 3: 5' clay; 20" - 30" silt, f ss; 13' clay; 13' ss, much lam veg, esp low in unit, Q at 3'; 8 1/2' f ss, minor veg.

Quarry 4: 13' xs bd ss with clay peb - clay peb, lam veg, rtlts 100 yds S, 2' clay clast near Q, Q at 3'; 9' clay, veg in lower part, 1' ss at 4', some rotted bone.

Quarry 5: clay; 5' f ss; 21' clay; 13 1/2' - 15' xs bd ss, some clay peb, veg, Q at 9'; 30" - 50" ss. with veg, clay peb, round bone frag; 3' ss, lam veg.

Quarry 7: 12' xs bd ss, finer in middle, xs bds in clay, veg-large clay clast; 5" persist lam veg; 15' f ss, silt lam, 1" xs lam, persist Fe st layers; 3' - 6' clay; 9' xs bd ss, clay, chert, quartzite peb at base, 5" clay clasts at 3', Q at base.

Quarry 9: 17' ss, 15% lam veg, some clay peb, clasts 12" long in top 4', Q at 1'; 8" Fe st; 4 1/2' clay, silty in upper half; 10' f ss; 2' brn veg clay.

Quarry 12: 26' xs bd ss, local 18" veg at 18'; 14 1/2' silt, silty clay, rtlts low in unit, plant debris above; 7' xs bd ss; 4' silty ss low in unit, clayey silt at top, v f clay peb, bone at top; 13' ss, clay peb first 2', persist clay layers up to 4" thick in upper 2/3; 11' - 13' silty clay with plant debris, ss at 6', clay peb, bone at top; 23' xs bd ss, red lam veg, local clay peb; 19' clay, silty clay; 14' ss, 25% irreg silty layers, 5" Fe st at top; 9 1/2' xs bd ss, veg, clay peb at 8", Q at base; 8' brn silt, plant debris.

Quarry 13: 5' ss; 7 1/2' ss, clay peb abundant, rtlts 20' from Q at same level, Q at 2 1/2'; 8' xs bd ss, lam veg, clay peb at top.

Quarry 15: clay; 8' xs bd ss, clay peb at base, some Fe st; 6' ss, much Fe st; 7 1/2' xs bd ss, Fe st at 3'; 5' xs bd ss, lam veg, some clay, Fe st; 56" thin ss, inlyrd with clay, much plant debris, some clay peb, Fe st, Q at base; 8 1/2' ss, clay at base with plant fossils, Fe st at top; 13' brn clay, inlyrd ss; 4' ss.

Quarry 16: 2' clay peb ss, bone; 4' ss, 3' xs bd, some lam veg, 12" clay clast, Q at 15"; 50" ss, truncates lower ss, lam veg near top, bone; 10" clay; 18" ss, clay peb, veg.

Quarry 17: 15' f ss, clay inlyrd in top 2', Q at base; thick clay.

Quarry 18: 9' xs bd ss, clay peb in top 18", Q below peb; 10' xs bd ss, much lam veg; 11' clay, silt; 5' yel clay; 1' veg-rich clay; 2' ss; 2' ss, clay; thick clay.

Quarry 19: 11' xs bd ss, clay peb at 10'; 18" xs bd ss, lam veg, Q at base; 7 1/2' xs bd ss, lam veg; 5' f ss fines to clay; clay.

Quarry 20: 11' xs bd ss; 15' ss, lam veg, clay peb, Q at 9'; clay.

Quarry 21: 18" ss, clean low in unit, clay, Fe st higher, Q at base; 12" ss, clay; 11" ss, clay; 2' silt, clay, veg, with ss inlyrd; 1' silt, ss; 5' brn veg clay, some ss inlyrd; 8' ss, clay peb at base, several lam veg.

Quarry 22: 8' silt, many sand bodies to 12" long (foundered?); 7' ss, finer at top; 5 1/2' clay; 18" ss, some clay peb; 25" silt; 2' ss, 6" clay below Q, Q at 1'; 5 1/2' clay, silt, some veg; 4' ss, clay peb, bone at base, lam veg above.

Quarry 24: 14' brn clay; 8' ss, lam veg, clay peb, small bones near top, Q 6" below top; 2' ss, clay; 4' xs bd ss.

Quarry 26: 19 1/2' xs bd ss with clay peb, lam veg, Q at 1'; 6' clay, thins N; 15' ss, finer near top, lam veg low in unit, 7" clay 2' from top; 16' f ss with silt; 6' clay.

Quarry 27: 6' yel v f ss; 16' silt-clay and clay, with some plant debris; 40' xs bd ss, 2' clay, clay peb at 8', inlyrd silt top 5', Q at 31'; 13' clay, silty clay; 5' ss.

Quarry 28: 10' ss, inlyrd silt; 14' clay; 11' ss, lam veg; 1' - 2' lens clay peb; 13' xs bd ss, 6" clay peb at 8 1/2', Q here.

Quarry 30: 13 1/2' xs bd ss, lam veg; 1' - 2' clay peb; 6' xs bd ss, much lam veg, 1" silt in middle, Q 1' above base; 4' ss, inlyrd silt; 28" clay, some ss; 5' ss, some clay.

Quarry 31: 15' clay; 18' xs bd ss with minor lam veg, clay peb at 15', Q at 1' - 2'.

Quarry 32: 28' clay, 30" silt-f ss at 15'; 6' xs bd ss, lam veg; 9' finer ss, silty near base, Q at 2'.

Quarry 33: 8' ss; 40" covered, Q here; 7 1/2' ss, rtlts lower 2/3, silty upper 1/3; 6' ss, silt lam, rtlts; 1' - 1 1/2' brn clay, veg; 8' ss, clay peb and lam veg low in unit, thin clay high; 7' clay.

Quarry 34: 30" ss, fines to clay, Q at 20"; 27" clay, silt; clay.

Quarry 35: 6 1/2' ss, clay peb, veg, Q at 2'; 15' persist clay; 14' xs bd ss; 11' ss, some veg, Fe st; 2' silt, clay; clay.

Quarry 36: clay; 2 1/2' - 8 1/2' ss; 25' brn clay, silt, inlyrd ss in large xs bd; 30" ss, some silt; 6' ss, siltier with less veg towards top; 13' ss, some silt, clay peb, lam veg, Q at 1'.

Quarry 37: 12' f ss, some veg, many silt and clay layers, Q at base.

Quarry 38: clay; 15 1/2' xs bd ss; 2' ss, silt; 8' silt-clay, some veg, inlyrd ss; 6" ss, clay peb, bone, Q here; 2' - 5' brn clay; 39' ss, clay peb, snails, veg low in unit, some Fe st with rtlts; 30" clay, ss, some Fe st; 5' ss, top half inlyrd clay; clay.

Quarry 39: 22' clay, inlyrd ss in 4' xs beds; 16' ss, lam veg; 7' silt, ss, thins S; 18' ss, bone, Q low in ss.

Quarry 40: 8' v clean f ss, Q at 6'; 4' clay; 2' ss, some clay; 4' clay 13' ss with lam veg, clay peb low in unit, 3 1/2' yel ss, veg; 7 1/2' ss; 6' lam veg, ss, passes N to ss; 2' lam veg; 8' ss; 7' clay, lenses out S.

Quarry 41: clay; 4' ss, clay peb, bone conc top half, Q at 6"; 11' f ss, lam veg low in unit; 30" lam silt-f ss; 2' f ss; 9' clay.

Quarry 42: ss; 4' ss, inlyrd clay; 13' - 15' clay; 18' - 20' ss, intrafm congl of lam veg, clay clasts, some Fe st, Q at 2'; 9' ss; clay.

Quarry 43: clay; 17' ss, lam veg, Fe st, bone at base, Q at 4'.

Quarry 44: clay, 7' xs bd ss; 4 1/2' ss, much veg, clay low in unit; 6' ss, much lam veg, Q at base; 10' ss, clay peb bone conc in middle; clay.

Quarry 45: 4 1/2' ss; 2' clay with sand bodies (q.v. Q 22), worn bone fragments at base; 21' ss, lam veg at top, Q at 9'; 4' clay; f ss.

Quarry 46: 5' xs bd ss; 20' ss, lam veg, Q at 14' in clear ss.

Quarry 47: 38' clay, rtlts, ss at 11' and between 18' - 23'; 3' ss, lam silt at top; 8' clay, veg, rtlts; 5' xs bd ss, veg; 22' - 25' ss, silty low in unit, veg, clay, high; 22' - 25' clay, silty clay, inlyrd ss in large xs bd; 1' ss, veg; 2' silty clay; 20' ss, much veg, clay peb low in unit, bone, Q at base.

Quarry 48: 45' xs bd ss, minor clay peb, Q at 8'; 37' silt, silty clay, minor sand in middle; 35' xs bd ss.

Quarry 50: 10' clay; 30' xs bd ss, lam veg, lens of clay peb, bone; 6' - 9' clay; 12' ss, xs lam veg, Q at base; 10' clay, silty at base.

Quarry 52: 4' - 8' silty clay; 37' xs bd ss, clay peb above 18', lam veg 25' to 30', Q at 4'.

Quarry 54: 4 1/2' f ss, lam veg low in unit, Q at base; 6' xs bd ss, local lam veg or clay peb at base; 20" silt, f ss; 30" ss, clay peb low in unit; 15' clay, 1' ss at 4'.

Quarry 55: 4' clay; 16' xs bd ss, some silt at 2', 5', lam veg low in unit and at 13', Q at 9'; 20' silt, silty clay, clay with

bone, plants at base, rtlts at top.

Quarry 59: 4' clay; 4' ss, silt and clay layers; 10' xs bd ss, lam veg low in unit, Q at 1'.

Quarry 60: clay; 3' ss, bone at base; 5' xs bd ss, Q at 2'; 7' xs bd ss, lam veg with clay peb and bone low in unit.

Quarry 62: 7' clay; 8' plane lam ss, thins S to 3' thick, veg low in unit, bone conc at base, Q at 3'; clay.

Quarry 65: clay, contact rises 2' in 15' S; 6' xs bd ss, clay peb at base, Q at base; 14" silt-f ss; 2' ss; 6' brn clay, wedges out N; 1' ss; 5' silt-clay with ss inlyrd to the N; ss.

Quarry 66: clay peb ss, bone conc; 28' xs bd ss, lam veg at 18", 8', 19', clay peb at 22', veg top 4', Q at 6'.

Quarry 68: 8' ss, silty near top; 12' - 18' clay; 28' xs bd ss, local clay peb, bone at base, minor lam veg low in unit, Q at 15'.

Quarry 69: 5 1/2' ss, veg low in unit; 15' inlyrd ss, veg, lam veg, clay peb, minor Fe st, Q at base.

Quarry 70: clay; 14' xs bd ss; 21' xs bd ss, minor clay peb; 4' silt-f ss, Q at 30"; 7' xs bd ss, lam veg.

Quarry 71: 16' xs bd ss, large clay clasts upper 1/3; 10" ss low in unit, silt-f ss high; 14" ss, veg, clay peb, clay, Q here; 12' ss, lam veg, esp at 8', persist Fe st at 9'; 11' silt, inlyrd f ss, lam veg, clay, Fe st.

Quarry 72: inlyrd silt and f ss; 4' clay peb ss, Q at base; 9' xs bd ss, lam veg in middle.

Quarry 73: 36' xs bd ss with clay peb, minor silt at 26', minor veg

upper 1/3, Q at 20'.

Quarry 74: 32' ss, Fe st low in unit, Q at 22'; 4 1/2' xs bd ss; 14" ss, silt, v small clay peb; 3' veg ss, ripple drift.

Quarry 76: 14" f ss, minor clay; 19" clay peb ss, some bone, veg; 4' ss, some veg, Q at 3'; 3' silty ss.

Quarry 77: 13' - 15' xs bd ss, xs lam veg; 2' lens clay peb, bone; 2' ss, Q here; lam veg 10" - 13"; 9 1/2' ss, veg, lam veg; 8' ss, some lam veg, clay peb, bone conc at top.

Quarry 79: 2' lam silt, inlyrd f ss; 4' f ss, 8" silt in middle; 2' - 3' lma silt, silt-clay; 12" f ss; 7" silt, rtlts; 10" - 17" f ss; 4 1/2' ss, silty low in unit, clay high; 1 1/2' - 3' silt, silt-clay; 17' xs bd ss, local lam veg, clay peb bone conc at 4', Q at 30", 5' lens lam silt, minor ss; 10' ss, silty at top.

Quarry 81: thick ss; 4' - 8' xs bd ss, clay peb, lam veg, low in unit; 2' - 4' clay, 1' lam veg below thickest clay; 16" clay peb ss; 6 1/2' xs bd ss, lam veg, Q at 4'; 23' ss, clay peb 12' - 15', lam clay clasts to 4" long at 16', veg, clay peb top 3'; 15' lam veg ss, silt, plant fossils; 10' ss; thick, persist clay.

Quarry 82: 15' ss, small scale xs bds, some clay peb, veg low in unit, lam veg high, Q at base.

Quarry 83: 17' xs bd ss, lam veg, clay peb from 2' - 4', one 3' clay clast, Q at 10'.

Quarry 84: 10' ss, lam veg esp low in unit, clay peb, ripple drift low in unit, top 5' fines to silty ss, Q at 6 1/2'; 15" silt, silty ss, clay; 15" ss.

Quarry 85: 19' xs bd ss; 3' f ss, Fe st, some clay peb, Q at 1'; 15" silt, some ss; 18" clay, veg; 9' xs bd ss, lam veg at base; 20' clay; 8' ss.

Quarry 86: f ss, Q here; 40" silty clay; 9' inlyrd clay, silt, some ss; 4' brn clay, minor ss; 10' brn clay, ss layers; 8' ss, layers of brn clay; 6' f ss, silt, clay.

Quarry 87: 5' ss, fines to top, Q at 1'; 9' clay, silty near top; 8' ss, minor lam veg; 12' clay, 1' ss at 7'; 2' clay peb ss; 14' xs bd ss, lam veg, clay in top 6'; 4' clay.

Quarry 88: Q sediment covered by slump; 3' above Q: 13' ss, much inlyrd silt, clay.

Quarry 92: clay; 7' ss, silt; 7' clay, f ss inlyrd; 6' ss; 4' ss, much inlyrd silt; 8' ss, clay peb at 30", Q at 1'; 4' clay, silty clay, plant fossils at top; 2' ss.

Quarry 93: 23' xs bd ss, clay peb at 4', Q at 5'; 5' clay; 5' ss, bone at base; 15' ss, inlyrd silt, clay; 4' clay.

Quarry 94: 5' clay; 20' xs bd ss, minor lam veg, silt, Q at base; 4' clay; 20' ss, lam veg, bone at base.

Quarry 95: clay; 14' ss, some clay peb, lam veg, Q at 2'.

Quarry 96: 17' silt, silty clay; 17' ss, xs bds low in unit, silty towards top; 4 1/2' clay, silty clay; 50' xs bd ss, 4' clay peb at 5', top 1/4 silty, Q at 28'.

Quarry 97: 11' xs bd ss; 12" - 30" lens clay peb, bone; 40' xs bd ss, clay peb at 13', lam veg at 18', some rtlts, silty top 10', Q at 15'.

Quarry 98: 4' clay, silt, rtlts near top, veg; 14' xs bd ss, lam veg, clay peb at 3', Q at 1'.

Quarry 101: 10' ss, persist horiz layers of silt; 9 1/2' clay; 13' f ss, minor inlyrd clay; 7' ss, clay inlyrd; 19' clay; 4' xs bd ss; 3' clay peb ss, bone conc; 11' ss, xs lam veg; 11' ss, Q at 10'; 27' clay, veg clay; 8' silt, f ss.

Quarry 102: 12' ss, much lam veg, some clay peb, clay clasts to 3" long, Q at 7'; 20" silt, veg; 3' ss, lam veg low in units; 16" lam silt-clay; 5' ss, much lam veg; 13 1/2' ss; 2 1/2' - 6' clay; 31' ss, lam veg, minor clay low in unit; 24' clay, silty clay, silt; 18' ss, minor lam veg, silt top 4'.

Quarry 103: 3' clay; 15' xs bd ss, clay peb at base, lam veg except top 4', Q at base; 20" clay; 6 1/2' ss; 13' clay; 15' xs bd ss, clay peb at base, lam veg.

Quarry 104: 25' clay, silt, silt-clay, minor ss, Q at 23'; 11' silt, silty ss, rtlts 20' ss.

Quarry 106: 16' f ss, lam silt near top; 12' clay; 27' xs lam veg ss, Q at 7'; 3' silt, plant debris; 30" ss, lam veg; 9' silt, silty clay, plant debris near top; 1' - 3' xs veg ss, clay peb; 21' lam silt low in unit, silty clay middle, sandy silt high; 27' clay, coally ss, silt, 1' poor coal at 14', 18" coal at 18', top 5' coally; 12' clay low in unit, silty middle, plant fossils, sandy at top.

Quarry 108: 16' clay; 25' xs bd ss with lam veg, clay peb at base, 2', silty near top, Q at 30".

Quarry 110: 16' ss, minor silt lam; 33' - 38' silt, silty clay, veg low in unit, clay middle, sandy with rtlts high; 22' xs bd ss, 1' clay peb at 8', silty at top, Q at 1'; 12' silt, silty clay, veg low in unit; 9' silty ss, veg; 12' silt, ss lam low in unit; 9' silty ss, veg; 12' silt, ss lam low in unit, clay high.

Quarry 111: 3' ss; 16' silt, silty clay, plant fossils; 21' ss, silty with plants at top, Q at 2'; 10' silt, inlyrd ss in large xs bd.

Quarry A: 20' xs bd ss, lam veg at 2', clay peb upper half, Q at 8'.

Quarry B: thick clay; 7' xs bd ss, some silty lam, Q at base; thick clay.

Quarry C: clay; 3 1/2' silty ss, veg, Q at base; clean ss.

Quarry D: Q in silty ss above thick xs bd ss; 6' silty ss; clay.

Quarry E: Q in f ss with silty lam.

N.B. All sections measured from bottom to top.

List of abbreviations:

brn: brown
clay: claystone
conc: concentrate
congl: conglomerate
esp: especially
f ss: fine sandstone
Fe st: ironstone
frag: fragment
horiz: horizontal
inlyrd: interlayered
intrafm: intraformational
irreg: irregular
lam: laminated
lam veg: laminated vegetable unit
N: north
peb: pebble
persist: persistent
Q: quarry
rtlts: rootlets
S: south
silt: siltstone
ss: sandstone
v: very
v f: very fine
veg: vegetable
xs bds: cross-beds
yel: yellow

FIG. I. DINOSAUR PROVINCIAL PARK
ALBERTA